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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

A GIS-BASED PARKING DEMAND ANALYSIS AND SITE SELECTION FOR PARKING AREA: PENDIK-ISTANBUL CASE

AHMAD SHEKIB IQBAL

A THESIS SUBMITTED FOR THE DEGREE OF

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PROF. DR. ARIF CAGDAS AYDINOGLU

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T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

OTOPARK ALANLARINDA CBS-TABANLI TALEP ANALİZİ VE YER SEÇİMİ: PENDİK-İSTANBUL ÖRNEĞİ

AHMAD SHEKIB IQBAL

YÜKSEK LİSANS TEZİ

HARİTA MÜHENDİSLİĞİ ANABİLİM DALI
JEODEZİ VE COĞRAFİ BİLGİ TEKNOLOJİLERİ PROGRAMI

DANIŞMANI
PROF. DR. ARİF ÇAĞDAŞ AYDINOĞLU

GEBZE

2020

GEBZE TEKNİK ÜNİVERSİTESİ	**YÜKSEK LİSANS JÜRİ ONAY FORMU**

GTÜ Fen Bilimleri Enstitüsü Yönetim Kurulu'nun 23 / 01 / 2020 tarih ve 2020/05 sayılı kararıyla oluşturulan jüri tarafından 21/02/2020 tarihinde tez savunma sınavı yapılan Ahmad Shekib IQBAL'ın tez çalışması Harita Mühendisliği Anabilim Dalı Jeodezi ve Coğrafi Bilgi Teknolojileri Programında YÜKSEK LİSANS tezi olarak kabul edilmiştir.

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SUMMARY

With the growing population and increasing number of vehicles, there has been a parallel increase in demand for parking spaces. Large cities are suffering from the lack of parking spaces. Parking spaces are one of the significant parts of the modern urban transportation system and traffic management; having significant effects on decreasing traffic loads. Finding parking spaces has become a major challenge for the urban transportation system especially in the downtown of metropolises. This thesis aims to determine parking demand by implementing two different approaches. The first approach is the integration of Geographic Information System (GIS) with the Analytical Hierarchy Process (AHP). Concomitant use of GIS and AHP represents holistic approaches capable of integrating multiple essential parameters simultaneously for effective land resource allocation. Second approach is Parking Demand-Supply analysis performed by using map algebra in the GIS environment. After calculating and discussing parking demand with two methods, the location-allocation methods of network analysts were implemented to allocate parking locations based on parking demand. In conclusion, we foresee the GIS with AHP approach to be a useful data integration in GIS-based solutions for accurate and better land resource allocations. On the other hand, second approach is a novel and advanced data processing approach that determines the facility locations more accurately and could be applied to transportation planning of developed cities to support the urbanization.

Key Words: GIS, AHP, Parking Demand, Location-Allocation, Transportation, Parking Site Selection.

ÖZET

Son yıllarda artan nüfus ile birlikte otomobil sayısında yaşanan artış, otopark alanlarına olan ihtiyaç ve talebi artırmıştır. Özellikle, büyük şehirlerde otopark alanlarının yetersizlik olması ciddi park problemlerine neden olmaktadır. Araçlar için ayrılan park alanları, trafik yoğunluğunun azaltılmasında önemli etkiye sahip olduğundan otoparklar modern kent ulaşım sisteminin önemli parçalarından biridir. Ancak, günümüzde uygun otopark yeri bulmak, büyük şehir merkezlerinde büyük problem olmuş ve kent ulaşımı içerisinde çözümlenmesi gereken en önemli sorunlardan biri haline gelmiştir. Bu tez çalışmasında, otopark taleplerinin belirlenmesine yönelik iki farklı yaklaşım önerilmektedir. Birinci yaklaşımda, Coğrafi Bilgi Sistemleri (CBS) ve Analitik Hiyerarşi Yöntemi (AHP) entegrasyonu ile etkin otopark alanları için kaynak tahsisinde birden çok parametrenin eş zamanlı analizi yapılarak bütünsel bir yaklaşım geliştirilmiştir. İkinci yaklaşımda ise, CBS ortamında harita cebri kullanılarak Otopark Arz-Talep analizi ile öncelikli otopark talepleri hesaplanmıştır. Bu yöntemlerle otopark taleplerinin belirlenmesinin ardından, CBS ortamında araç park yerlerinin tahsis edilmesi için ağ analizleri uygulanmıştır. Sonuç olarak, AHP yaklaşımıyla CBS'nin eş zamanlı kullanılmasıyla, doğru ve daha iyi yer seçimi için CBS tabanlı çözüm ile veri entegrasyonu sağlanacağı öngörülmektedir. Diğer taraftan, ikinci yaklaşım ise yer seçiminin daha doğru bir şekilde yapılması ve gelişmiş şehirlerin kentleşmesini desteklemek için ulaşım planlamasına uygulanabilecek yeni ve ileri bir veri işleme yaklaşımıdır.

Anahtar kelimeler: CBS, AHP, Otopark Talebi, Location-Allocation, Ulaşım Otopark Yeri Seçimi.

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LIST of ABBREVIATIONS and ACRONYMS

Abbreviations and Acronyms	Explanations
GIS	: Geographic Information System
MCDM	: Multi Criteria Decision Making
AHP	: Analytical Hierarchy Process
COPRAS	: Complex Proportional Assessment
OWA	: Over Weighted Analysis
TSE	: Turkish Standardization Institute
IUAP	: Istanbul Transportation Master Plan
P&R	: Park and Ride
AASHTO	: American Association of State Highway and Transportation Officials
ESRI	: Environmental System Research Institute
ERS	: Emergency Response Services
DEM	: Digital Elevation Model
TAC	: Travel Absorption Center
RTMS	: Remote Traffic Microwave Sensor
TAZ	: Traffic Analysis Zone
MA	: Minimize Impedance
MC	: Maximize Coverage
MF	: Minimize Facilities
MA	: Maximize Attendance

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1. INTRODUCTION

The recent technological advancement and sophistication have led to increased urbanization; with more people moving to urban areas. The increased number of people has characteristically negatively impacted the urban transportation system through a rapid increase in vehicle numbers. Therefore, most of the large and developed cities suffer from lack of parking spaces. Parking spaces play an important role in modern urban transportation and traffic management system. Efficient parking spaces decrease traffic load and reduce marginal parking, hence, indirectly increasing street widths and improving the motion of vehicles. Locating parking area is the main issue in transportation planning, and wrong decisions cause inefficient traffic management, urban transportation system, economic loss and increases environmental degradation [1]. Regions with residential, business or commercial activities usually require parking spaces. Supplying sufficient parking spaces to meet parking demands in such regions may rectify marginal parking [2]

Geographic Information System (GIS), as a science of geographic analysis, is a worthy scientific approach to determine parking demands. The ability of GIS in selecting suitable sites for parking lots is well captured in scientific literature. The use of GIS in the field of c analysis increases the accuracy of Geomatic works and reliability of results. Determining parking demand is directly related to disparate parameters and their relative importance. Traditional methods of determining parking spaces are limited by the narrow spectrum of parameter evaluation during parking space location. Therefore, in some cases, this makes parking spaces to be located away from the travel absorption centers and far from busy streets, which have negative effects on traffic loads. Thus, it’s essential to develop an approach that considers all the effective parameters simultaneously and also meets the requirements for parking areas in transportation planning for large and developed cities.

1.1. Literature Review

Various studies have been conducted with the use of Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) as one of Multi-Criteria-

Decision-Making (MCDM) methods. Developments in computer technology, the multiplication of data sources and types, and the use of geographic and non-geographic data in GIS together with AHP have also taken place in various study areas. However, as far as it is known, no previous research has investigated parking Demand-Supply analysis approach to determine parking demand, just used in Development of Business Strategies for Vehicle Parking Areas in Istanbul City [3]. Moreover, few studies have focused on selecting the best locations using the location-allocation techniques of network analysts in a GIS environment. The location-allocation techniques could provide scientific support for the planning and allocating facilities. Some of the studies are summarized below;

Palevičius et al. [4], conducted a study in Lithuania, the districts of Vilnius for evaluating parking development. Level of car ownership, level of public transport development, the density of population, the total area of built-up territory, number of populations, street density, number of workplaces and number of employed people were used as the criterion. The criterion weights were determined by using Analytical Hierarchy Process (AHP) method. The parking lots rationality was determined by using the Complex Proportional Assessment (COPRAS) method.

Eskandari and Nookabadi [5], in an article named "Off-Street Parking Facility Location on Urban Transportation Network, Considered Multiple Objectives" in Isfahan of Iran, considered four objectives and four criteria for determining Off-street parking facility. Minimizing traffic congestion, maximize demand coverage, minimize the walking distance, and minimize different costs were pointed as objectives of the study and parking demand points, the flow of entry points, locations of candidate parking, and location of existing parking were pointed as criteria. Based on objectives two multi-objective models have been proposed, finally, the ε-constraint method was applied to solve the proposed models and determine the best candidate point as the new off-street parking lot.

Obaid Alshwesh [6], in a Ph.D. research study in order to support the decisions that made about the optimum location of facilities across three case study areas in the UK and Kingdom of Saudi Arabia, investigated the interactions between a selection of three interpolation techniques, and a selection of four location-allocation problem types in the GIS environment.

Hosseinlou et al. [1], in a research study in the regional of Tehran, find a suitable location for parking spots. The price of land, accessibility to transportation terminals, accessibility to passages and distance from travel absorption centers were the effective factors considered in the GIS environment. The effective parameters were weighted by the AHP method and finally, the weighted parameters were combined using the Fuzzy algebraic sum.

Algharib [7], in Kuwait City, the location-allocation models and a number of GIS functions were utilized in order to support the geographic planning for fire stations. He applied the P-median model to see if all demands are covered the whole districts in Kuwait City or additional fire stations are required and where the optimum locations will be for them.

Kumar and Biswas [8], in a case study of the Shimla municipal area, Shimla district, Himachal Pradesh, India, identified the potential sites for urban development in the mentioned area by using GIS and Numerical multi-criteria-evaluation (MCE) technique. Five criteria have been used for land evaluation; slope, proximity to the road, land use/cover, lithology, and aspect. The criteria have been weighted by the AHP method and the final suitability map has been prepared.

Krasić and Lanović [9], in Zagreb, Croatia, a research study was defined in order to determine the location of park and ride (P&R) facility. For planning P&R facility, the size of the site, the multifunctional character of P&R location, the realization of P&R from technical and financial viewpoints, quality of public transport service and access to P&R locations were considered as the criterion. The alternative which was identified was evaluated by the AHP method.

Demir [10], applied research for the use of multi-criteria-decision-making techniques to find the optimal locations of car parking areas in the Ataşehir, Kadıköy, Üsküdar, and Ümraniye districts of Istanbul city. The criterion has been categorized under transportation type, land use and finance criteria. The weights of criterion have been specified by Fuzzy AHP.

Aliniai et al. [11], conducted a research study in the city Tehran, Iran for parking lots site selection. Distance from passages, real estate cost, distance from travel absorption centers, and suitable land use were chosen as criteria. Whereas, the unsuitable land uses for parking lots, such as historical places were considered as constraint factor and excluded from analysis. The chosen criteria were weighted using the AHP method afterward the layers were combined by the Boolean method and finally, the results were tested by the fuzzy Ordered Weighted Average (OWA) method to select the most suitable sites for public parking lots.

Haldenbilen et al. [12], in the study conducted for Denizli province, the existing off-street parking in the city center of Denizli were researched, their capacities and occupancy rates were determined, and for parking demand, the future prediction was also made. In the research, according to the number of houses, parking demand after 20 years, number of residences after 20 years, in accordance of a certain rate of increase, for every 5 houses, 1 parking lot were calculated. On the basis of the number of vehicles, the number of vehicles after 20 years in accordance with the geographical rate of increase was calculated and in the city center for every 5-8 vehicles, 1 parking lot was considered.

Al Garni and Awasthi [13], used GIS-AHP based approach for site selection of solar photovoltaic (PV) power plant Sudia Arabia, the aim of this research was to select and evaluate the best location for a solar PV project. This model considers economic factors and technical factors as the main criteria. The solar analyst tool in ArcGIS is employed and the AHP method is applied to calculate the weights of criteria and compute the land suitability index. Finally, the weighted overlay analysis is used to prepare the optimal sites for utility-scale PV solar project.

1.2. Research Objective and Methodology

The objective of this dissertation is to design a method for determining parking demand and allocating parking areas in urban metropolitan areas and Pendik district is used as a case study to test the method.

As a methodology, in this thesis, we implemented two different approaches to determine the parking demand and used in Pendik district as a case study. The first approach is the integration of Geographic Information System (GIS) with the Analytical Hierarchy Process (AHP). GIS is widely recognized for its capabilities in performing geographic analysis and is designed to manipulate and manage geographic data from different sources to increase the efficiency of geographical positioning [14]. AHP, as a Multi-Criteria-Decision-Making (MCDM) technique, allows personal judgments in a reliable way, easy to understand, and does not require complex mathematics [15]. The second approach is Demand-Supply analysis by using map algebra in a GIS environment. Additionally, the location-allocation analysis tool of network analyst was tested to allocate parking locations based on parking demand.

In the first method, geographical data of different criteria; point, line and polygon geometries were transformed into raster layers by applying vector to raster transformation and geographic interpolation and then included in Multi-Criteria-Decision-Making process. The weight values of criteria and sub-criteria were assigned from the evaluation of the questionnaire survey which was distributed to experts, managers, and users. As a result, by combining the layers of sub-criteria than criteria through using their corresponding weights, the resulting layer was prepared and the pixels with high parking requirements were determined.

In the second method, the geographical data were converted to point geometry by using the feature to point tool. In parking Demand-Supply analysis, different operations of map algebra were applied, and the fixed demand and dynamic demand of parking were determined. As a result, the parking demand was converted to raster datasets and pixels with high parking demands were calculated.

After discussing these methods, location-allocation analysis tools were used to allocate parking locations based on parking demand. In this process, four problem types of the location-allocation tool were implemented.

2. GENERAL INFORMATION

2.1. Car Parking and Parking Demand Factors

Parking is available for passenger cars. The car parking is an open or closed area or building where people are stopping their vehicles and leaving them unoccupied for more than a brief of time. The parking lots may be special places and structures, or they may be in the form of a building extension. Parking lots examples in buildings are shopping malls, hotels, hospitals, sports stadiums, residential buildings, roadside parking (marginal parking), and similar places. In addition, P & R facilities which are located on the outskirts of the city and close to the public transportation stations with the capacity of high passengers are also an example of the car parking.

The location where vehicle traffic is inactive is called parking. According to the Turkish Standardization Institute (TSE), the car parks cover the design rules of on-street parking, off-street parking and garage facilities for cars and other motor vehicles that meet the external dimension in urban areas, but it does not cover the business rules [16].

In other words, a parking lot is an organized surface or place that's desired for parking vehicles. Usually, the term of parking lots refers to the permanent and semi-permanent surface that has been provided for parking vehicles [17].

According to Austroads "Parking can be defined as the act of stopping a vehicle and leaving it in the one location for a period of time, whether or not anyone remains in the vehicle" [18].

2.1.1. Types of Parking Facilities

The journey of every private vehicle starts from a parking lot and ends in a parking lot. French city planner Gaston Bardet said, an automobile generally spends 2-3 hours per day in motion states, while spending almost 22 hours per day in a parking lot [19]. According to Comprehensive Transportation and Traffic Studies (2003), each private vehicle spends 5 to 10% of its total lifetime in moving around and rests its total lifetime spend in parking lots that are called stationary traffic, which is a vital problem for traffic management. Each parking covers an area between 15 – 30 m^2, on average each vehicle may park at least in two different places (home and office).

Parking areas vary according to locations and characteristics. This diversity is also reflected in the car parking features and requirements. Factors such as investment and operating cost, required area size and capacity are affected by the location of car parks.

Parking facilities are generally divided into two major groups:

On-street parking: The other name is curb parking, are those that provide parking along the roadsides. On-street parking can be on one side of the road or on both sides of the road. Usually, the location of on-street parking was determined by the government agencies. If the duration of parking is unlimited and free it will be unrestricted parking facilities. If parking is limited particularly in peak hours of the day and it may be free or payable it will be restricted parking facilities [20].

Off-street parking: As the name itself said “off-street parking” the parking that is located far from the streets and the vehicles are parked off the streets. Nowadays, off-street parking is a preferable option for mass storage of vehicles. Multistoried car parks, surface car parks underground car parks, and mechanized car parks are the off-street parking examples that contain the high capacity of vehicles. For efficiency of the parking system, the on-street parking divided into three categories:

Parallel parking: Vehicle owners park their vehicles on the side of the road parallel to the length of the road. The entering and leaving maneuver in the wide streets are comfortable than the angular parking, but it consumes the maximum length with the minimum number of vehicles, in the perspective of an accident [20].

Angular parking: Vehicle owners park their vehicles on the side of the street at an angle. When the angle has increased, the entering and leaving maneuver in the street will be decreased. The vehicles are parked in 30, 45 and 60 degrees to the road axis. The drivers should take care while opening the front door because it may be damaged the other parked vehicle, therefore the 45 degrees is preferable to park the vehicles [16].

Perpendicular parking: The passengers are parking their vehicles at 90 degrees to the road. It’s an impressive parking system especially for trucks who loading and unloading the goods in trade zones [16].

Another type of parking has existed in many different forms is the Park & Ride facility. P&R facilities are areas located on the outskirts of the city and serve as a transit facility between numbers of transportation types and the vehicles can be parked for long periods of time. The concept of P&R is defined by the American Association of State Highway and Transportation Officials (AASHTO) in the interim of Geometric Design Guide for Transit Facilities on Highway and Streets as "a facility which provides places where car or carpool users can park their vehicles during the day, and using a transit or carpool or vanpool system to reach their travel destinations. These P&R facilities may be served by one or more transit routes" [21].

The aims of P&R facilities are to encourage travelers to use the transit systems for reaching out to their destinations, which causes a reduction in traffic load. These facilities may also help to "increase the mobility options of travelers, increasing person time spend on the system, decreasing the number of vehicle trips, decreasing the greenhouse gas and air pollution associated with transportation, and decreasing congestion on transportation facilities" [21].

2.1.2. Parking Demand Factors

Parking areas are affected by many factors within the transportation system. The majority of these are factors such as land use status, cost of parking, car ownership, economic vitality and presence of public transportation systems. Particularly in places where the transportation system is adequate and accessible, the parking demand is relatively low. Nevertheless, in case of insufficient transportation, people prefer using special vehicles. Parking demand differs from one location to another.

According to Naasra "parking 'demand' refers to the amount of parking that is needed at a specific time and place". Vehicle ownership, the popularity of an area, the nature of the surrounding uses, availability of alternative forms of transportation and other external factors like fuel cost are mentioned as factors that affect the demand. The demand rates usually refer to the daily, weekly, seasonal or even annual basis. Therefore, the demand rates typically varied and vacillated by these cycles. For instance, demand in an office area will increase during the day and weak days though the demand will increase at restaurants and theatres places during the weekends or evenings [22].

Providing parking area is to meet the demand for parking. If parking is made to provide the need for services, it decreases traffic congestions and marginal parking. Therefore, the choice of a suitable location for the parking area is very important. While selecting locations of new parking lots, the problems of existing parking should be investigated. When parking areas are planned, the expectation of consumers should be taken into consideration, parking areas should be spread to the environment, the safety and traffic passages should be appropriate, open to development and new parking areas should have a relation with the roads system and existing parking areas [23].

There are a number of major factors that influence the parking demand, some of them are mentioned below [24].

Geographic location: By increasing density, accessibility of transit service and non-motorized travels, like walking and bicycling, vehicle ownership and use tends to decrease. When a reduction in vehicle ownership and use happened, the result of parking demand typically reduced in activity centers especially. The parking with secure areas and cheap fees near to the destination tends to raise up the parking demand.

Types of land use: Parking demand has been greatly impacted by types of land use in a specific place. Land uses impact the parking demand on a consistent basis such as entertainment places, drug stores, shopping malls, medical services, recreational facilities, office complexes, etc. Land uses also impact the parking demand in temporal variation. It affects parking areas during different times of the day to increase the customer attraction, for instance, coffee shops during the morning and evening and restaurant during the evening.

The other effect of land uses on parking demand is refer to the multiple destinations for a trip or car park sharing, one parking area can serve two or more than two destinations. For example, restaurants with retails, theatrical performances with restaurants and coffee shops with offices, associated only with one parking area [25].

Availability and attractiveness of public transport: Parking demand can reduce by the availability of competitively priced, repeated, attainable, reliable and attractive public transport at city and town centers. The other alternatives such as car sharing, travel blending (combining activities to reduce overall trips), walking and bicycling may also reduce the parking demand.

Availability and attractiveness of parking facilities: If due to heavy traffic and high price, the parking is not accessible or attractive for drivers then the parking demand may be reduced. If parking is well located and easily accessible at an appropriate price or free, the demand surely increased. When the price of parking decreases, the demand for parking generally increases.

Time of the day, weekly and seasonal variations: According to the time of the day, week and year, the parking demand differs for various land uses, considering the level of activity happening at a point in time. Each land use may peak at distinct times of the day, days of the week and months of the year.

Figure 2.1 shows the daily variation of the parking demand for different land uses, from the figure we can get that the demand for parking in a residential complex and restaurant area arises in the evening while the demand for parking at an office increases in the morning [26].

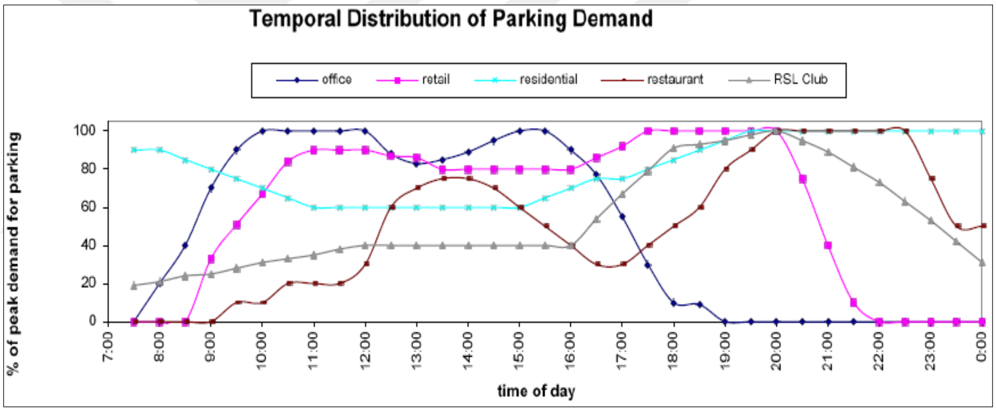

Figure 2.1: Typical example of hourly distribution of parking demands.

The alteration of parking demand by day of the week is given in Figure 2.2. This figure displays the percentage of variation of demand at a large tourist shopping and entertainment facility on the busiest day of the year. This figure indicates that the parking demand rises on weekends, and the demand reduces a lot on weekdays. This temporal variation of parking demand creates a rhythm when parking is needed and provides an opportunity for parking areas all over the city centers to share time [25].

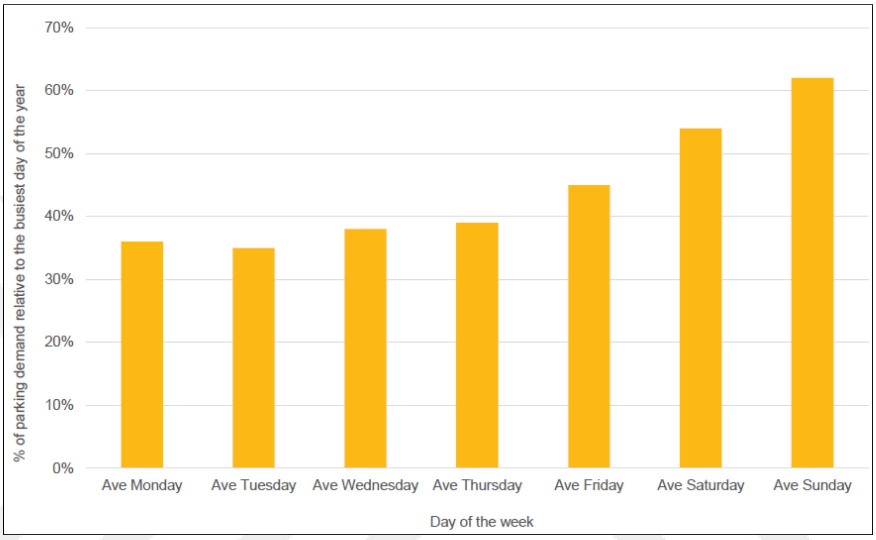

Figure 2.2: Typical example of weekly variation of parking demand for a tourist area.

Figure 2.3 illustrates the cycle of automobile dependency; this cycle shows that the parking areas together with the transportation system components follow each other. It is reflected that transportation based on the use of individual cars often affects other components in the system negatively and one of the components is increasing the requirements of parking areas. It seems that increasing the automobile leads to disrupt the balance in this system [27].

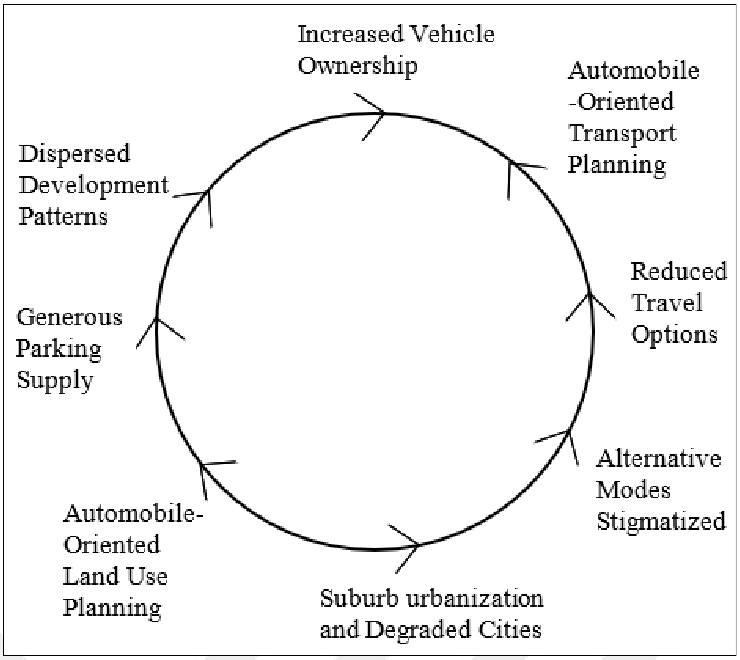

Figure 2.3: Cycle of automobile.

Another term is shared parking that refers to “shared parking means that a parking facility serves multiple users or destinations”. The motorists use the parking facility in different peak periods, as shown in Table 2.1. The frequency use of parking shared for buildings and facilities are separated from each other according to the hour of operation. The table is divided into weekdays, evenings and weekends. Mass use of shared parking refers to weekdays, most of them are office buildings. Evening and weekend groups refer to social and cultural activities. The most beneficial part of shared parking is sharing parking between different destinations. For example, theater and restaurant facilities can share the parking with office buildings, since the peak demand for theater and restaurant happens during evening and weekend, though the peak demand for office building happens during weekdays [28].

Table 2.1: Typical peak periods of various land uses.

Weekdays	Evening	Weekend
Banks and public services Offices and other worksites Park & Ride facilities Schools, daycare centers and colleges Factories and distribution centers Medical clinics Professional services Religious institutions	Auditoriums Bars and dance halls Meeting Halls Restaurants Theaters Hotels	Religious institutions Parks Shops and malls

The main factors that affect parking demand are shown in table 2.2. Considering these factors and after the complex processing within the transportation systems, the optimal location of parking areas has been determined accurately [29].

Table 2.2: Parking requirement adjustment factors.

Factors	Description
Geographic location	Vehicle ownership and use rates in an area
Land use mix	The range of land uses located within convenient walking distance
Residential density	Number of residence or housing units per acre/hector
Employment density	Number of employees per acre
Transit accessibility	Nearby transit service frequency and quality
Car sharing	Whether a car-sharing service is located nearby
Walkability	Walking environment quality
Demographics	Age and physical ability of residents or commuters
Income	The average income of residents or commuters
Pricing	Rating of priced parking lots
Parking & mobility management	Parking and mobility management programs are implemented at a site

Every city is different from each other in terms of geographic location, size, population, economic structure, distribution of employment and transportation infrastructure, therefore the problems are also different from each other. For example, many cities have developed in terms of industry, trade and tourism activities, in the result, the parking demand is getting high. In this condition, the parking problem requires a systematic approach to handle this problem in a hierarchy and at different scales [28].

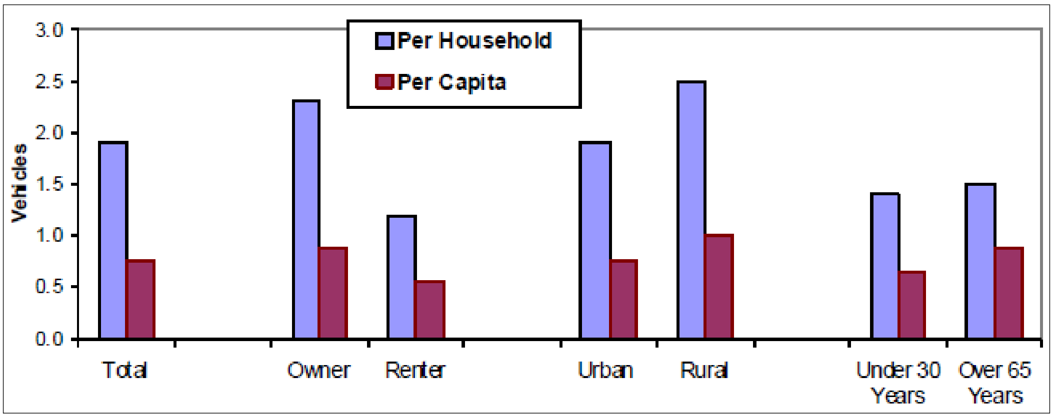

Figure 2.4: Vehicle ownership per household and per person.

Figure 2.4 indicates the housing tenure, location and age factors that affect vehicle ownership and parking demand. It observes that the renters, those who live in cities and those who are under the age of 30 years have low vehicle ownership; the owner, those who live in rural and those who are over the age of 65 years have high vehicle ownership.

There is another factor that affects car ownership such as household size, city size, population density, and transit service quality. Larger households tend to own many vehicles than smaller households. Different cities of a country have different rates of car ownership. By increasing of population density, the car ownership seems to be declined. Residential communities with various transportation systems will have fewer car ownership because they are willing to do more trips with transit systems than vehicle trips [29].

The parking facility is not limited to the problem of car ownership, it affects the whole society. The negative effects of parking facilities are observed in transportation, traffic, environment, economic and social relations. The parking facility is affected by demographic structure, socio-economic structure, land use, and accessibility. By increasing the population, the number of cars in cities is also increased parallel. Socio-economic activities in the city that spread by vehicles such as cargo, food delivery services, transferring of technical services and packages in the purpose of business affect the parking. Land use functions like offices and businesses, large stores, shopping malls, restaurants, residents, hotels, hospitals, conference halls are the major factors that greatly affect the parking [30].

Parking demand varies according to night and day parking behavior. A significant amount of transportation vehicles is remaining parked for a much longer period of time and some remain parked for a short period of time. People use private vehicles or public transportation to provide access to activities. Users use private vehicles for themselves, they can access to any activities at any time they want, their vehicles are in motion during access to activities and parked during doing their activities. The car parking can be shown in two structures according to day and night behavior [31]:

Long-term and continuous parking is during the night like parking around residential areas and workplaces. If the residents and workplaces are separated from each other and the trips are carried out by private vehicles, in this case, it requires parking areas for two vehicles during the day, one for the house and another for the workplace.

Short-term parking is for different activities during the daytime. Different activities cover daily businesses such as public services, education, shopping, entertainment, sport, and health. In the course of the day, the travel chain and the parking behavior are closely related to the arrangements of activities in time and place. For determining short-term activity places, the parking presentation and cost are considered as significant inputs.

2.2. Geographic Information System (GIS)

GIS is a computer system (hardware and software) capable of assembling, storing, manipulating and displaying geographically referenced information (i.e. data identified according to their locations) [32].

GIS is widely used in several disciplines such as land surveying, civil engineering, transportation, resource management, cartography, navigation, business planning, urban planning, and business analysis. GIS has the capability of analyzing both geographic and non- geographic data, this capability leads GIS to replaces the other information systems. For analyzing and managing of complex geographic information, it combines geographic and non- geographic data to create thematic maps [33].

Indeed, GIS is a science of geographic and non- geographic analysis used to support decision makers and strategic planners particularly when the issues are geographic. In the past, it was tough for investigators to study any geographic criteria in their analysis due to lack of GIS tools even if an investigator did, it was poor geographic criteria. Because at first, for analysis the required data was unavailable, and second even if the required data was available, there were no such systems to perform the complex analysis. Nowadays, by using GIS you are able to study complex geographic analysis. The function of GIS in computation and analysis of geographic criteria is undeniable. The GIS tools allow you to apply geographic and non- geographic criteria to solve optimum site selection problems [34].

Today's improved geographic information technologies like land survey and GPS, satellite imagery and Computer-Aided Design (CAD) data in vector and raster structure can be integrated into the data sets of GIS environment. In other words, GIS can handle geographic and non- geographic data from different sources at different scales. For instance, the location of transportation networks, recreational sites and administrative regions data can be acquired from local maps and regional distribution of land use data can be acquired from satellite images.

Geographic data sets first should be transformed into the computer environment understandably and the model selection should reflect the actual data. Geographic data can be presented in a graphic environment with the help of a computer in vector and raster model or presented by a hybrid model. According to the application requirement or the nature of data, an appropriate data representation model can be used in the study area.

Moreover, the data are stored and presented in the GIS environment as a layer of information. These separate layers are connected via their coordinate system in order to combine the data from several layers of information to present the real world. Figure 2.5 exhibits the layers of information in the GIS which reflects the real-world locations. Each layer presents a single issue in a specific area [35].

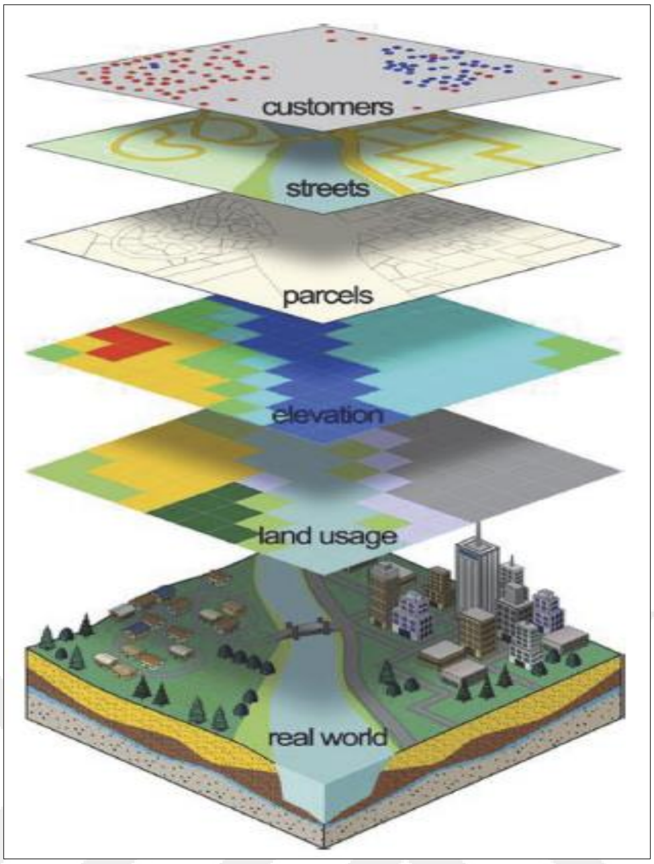

Figure 2.5: GIS layers of information.

According to the U.S. Geology Survey (2002), GIS has eight functional components that are explained below [32]:

Using data from various sources: A GIS can use and relate data generated from various sources about a location to generate useful information for queries. Geographic coordinate system (latitude, longitude, and elevation) are commonly determining the location of an object. In order to use data into GIS, the primary concern is that the source data can be located geographically. Likewise, a GIS can convert existing digital information or census data into map-like form, producing layers of thematic information in a GIS.

Data capture: Only the data in digital form can be used in GIS. Therefore, all data at first must be digitized then can be used in GIS. There are several techniques to capture that data. For example, an electronic scanning device scans the map and the points and lines of the map are converted into digits.

Data integration: A GIS can connect and integrate different kinds of data. Particularly, A GIS creates and analyzes new variables from the combination of other mapped variables. For instance, if road data and traffic accident data are available in a GIS, it’s possible to generate information about the roads that have more accidents and the roads that have no accident. The police station can use the generated information to apply policy for reducing accidents and increase roads safety (e.g., installation of traffic lights).

Graphic display techniques: In traditional maps the physical objects have been presented by using symbols and in topographic maps shape of the land surface has been presented by using the contour lines. Graphic display techniques make communications between map elements, rising the ability to analyze and extract information. GIS for presenting surface elevation generally uses the digital elevation model, which views the high elevation and low elevation in different colors.

Projection conversions: Before analyzing and manipulating the digital data in the GIS, the projection transformation of the data take place. Projection is a mathematical process of managing map data and it’s a basic principle of making maps. This includes conversion to a two-dimensional image from the three-dimensional real world in the computer screen and research forms.

Data structure: Digital data may be collected and stored from several sources in different ways. Therefore, data may have different structures and it may or may not be compatible. Accordingly, a GIS would transform data to a compatible structure from an individual or incompatible structure.

Data modeling: GIS covers two types of data models (raster and vector). Raster data models are illustrated by cells or pixels of the same size. Generally, land use maps are represented in the raster model. The vector model expressed the geographic features in GIS with three shape lines, polylines, and polygons.

Data output: After analyzing and manipulating the digital data or in other words after producing the maps in a GIS environment, the layers can be illustrated as graphics on the computer screen or printed on the research papers. A final note is that a GIS can generate thematic maps and other graphics, allowing users to visualize and simulate the potential solutions.

2.2.1. Geographic Data Models

The presentation and visualization of the real-world in the GIS environment are done by two models of data, vector data model and raster data model.

Vector data model: The vector data model illustrates the real-world by using points, lines and polygons which are expressed by the geographical coordinates. The point, line and polygon entities are fundamental static representations of real-world objects in terms of 2D dimensional [36].

A point entity expresses that the geographical extent of a phenomenon is limited by a location identified by one XY coordinates such as electric poles, wells. A line entity expresses that the geographical extent of the phenomena can be identified by sets of XY coordinates which are connected sequentially with each other like electric lines, roads. The clearest definition of polygon expresses that it is a homogenous representation of 2D area. In terms, XY polygon expresses the geographical extent of an object with the same start and endpoint such as parcels, building, and land use [36].

Raster data model: Raster data model is expressed by the combination of same size cells (pixels) in the grid structure. All or part of the map in a raster structure is defined by the pixel matrix of rows and columns in horizontal and vertical positions, such representations are also known as grid models. Generally, raster data assigned in two classes: thematic data and image data. The values in thematic raster data usually express some measured quantity or represent the classification of specific objects such as elevation or population. The values in image data illustrate the amount of emitted or reflected energy that has the value range of 0-255 colors like in satellite images and scanned images [37].

2.2.2. Geographic Analysis Techniques

The extraction and interpretation of the information through the data is done with the help of geographic analysis. Geographic analysis tools provide systems and tools for analyzing positional data and analyzing appropriate steps according to the requirements of an application. Mathematical models are used to search for solutions by different algorithms.

For many GIS applications, it provides a wide range of tools from the simple buffer and overlay analysis to complex regression analysis and surface analysis. In order to interpret the data in the most appropriate way, it is necessary to define the geographic problem such as finding the suitable site for car parking, and solving this problem needs analysis that was expresses in steps and sub-steps for the solution [38].

Geographic analyst tools are a key benefit of a GIS that you can apply various geographic operations to GIS data to extract new information in order to obtain a rich set of informative maps. A geographic analyst extension module allows users to develop a powerful geographic analysis for raster and vector data. By using geographic analyst tools one can find the answer to specific questions like, what is the most profitable place for the market you want to open?, how much pollution is in this lake, what is the population density of district A, provide the optimal transport ways by calculating travel cost [39].

For a better understanding of geographic phenomena during geographic analysis, the GIS data are being expressed by points, lines and polygons. The distribution of plant species, the epicenter of earthquakes, diseases, and accidents are expressed by points. The roads, rivers, electric lines and much more are expressed by lines, and the line at the same time can show the boundaries of fields. Province's and district’s boundaries, health zones, natural areas like vegetation and land are expressed by the polygon. However, this situation may vary according to the scale of the study [40].

2.2.2.1. Kernel density

Density illustrates where the point and line values spread or concentrated over a surface in the search area. The density function estimates in two methods: simple density and kernel density estimation. In simple density estimation the fallen points and lines in the field area are summed and then divided by the field area size to give the density value, whiles the kernel density estimation done same as simple density estimation, except those points and lines that fallen near to the center of raster cells are weighted more highly than those values that fallen near to the edge, in result we get the smother surface (Figure 2.6) [40].

Kernel density estimation is one of the geographic analysis techniques that applies to points and lines feature data sets. Obviously, the result of kernel density calculation in the GIS is the raster data type which each cell has a density value that is weighted according to the distance from the center of raster cells [41].

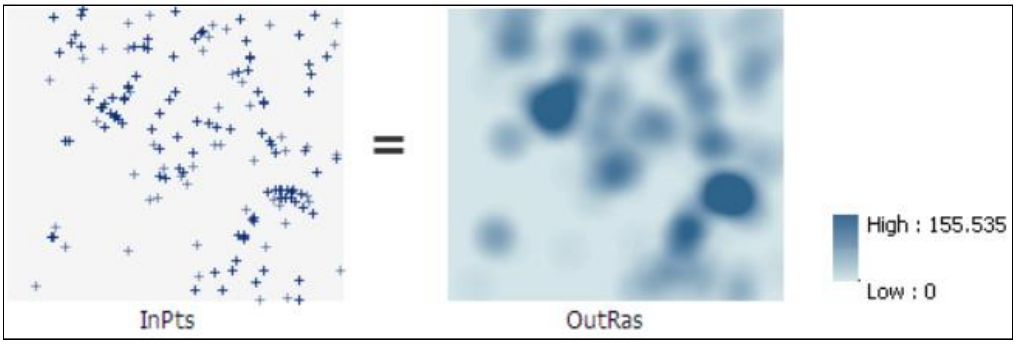

Figure 2.6: Surface density according to number of points.

The result provided by the kernel density is smoother and interpretable. This useful methodology implemented to smooth out the multivariate distributions and applied to smooth out the irregularities in the sparse data. With this advanced method, it is possible to classify and interpret such data [42].

2.2.2.2. Euclidean distance

The Euclidean distance tool is the most widely used tool for distance analysis. The objective here is measuring the straight-line distance from each cell to the nearest source. The object of interest identified by source, the source can be wells, roads, forest stand or a school. The Euclidean distance is measured from the center of the source cell to each center of cells.

The input source data can be a feature class or raster. If the input source data is a raster, the source cells must contain the valid values, while the other cells have NoData values. If the input source data is a feature class, before performing the analysis the source locations are converted internally to a raster.

The Euclidean distance measures the distance from the center of the source cell to the center of the surrounding cells. Euclidean distance has many applications in different fields, such as detection of flood zones, determination of shoreline, a distance of highways to specific areas. Additionally, Euclidean distance tool is used in finding the closest hospital for an emergency helicopter flight. On the other hand, this tool frequently used when creating a suitability map [38].

2.3. Analytic Hierarchy Process (AHP)

AHP is one of the Multi-Criteria-Decisions-Making (MCDM) methods that is widely used in different fields. This method was first submitted by a researcher named Thomas L. Saaty in 1980. The reason that AHP successfully and extensively used is referred to as the easy managing of multiple criteria, applying qualitative and quantitative data effectively and easy to understand. In addition, the use of AHP does not require complex mathematics [43]. Moreover, due to the pair-wise comparison, the judgments and computations are unchallengeable. AHP involves three main principals including decomposition of the problem, pair-wise comparison, and combination of priorities [44]. In the AHP method, the crucial issue is to develop a hierarchy structure which is broken down the problem into a hierarchy of goal, criteria, and sub-criteria. Creating the hierarchy structure is a fundamental process of the AHP method [45].

A hierarchy is a powerful method of classification used by the brain to order information that achieved from the experiment or from our own thinking to understand the complexity of the events around us and distributes the influences in order to expect a certain decision. The decision-making process is not isolated, but there is sort of factors that influence the decision. All can be considered as a network of influence in which hierarchies are the specific issue [46].

Figure 2.7 illustrates the hierarchy structure of AHP, which the topmost level is the goal, afterward continues with criteria, sub-criteria and the lowest point of the hierarchy model is the alternatives.

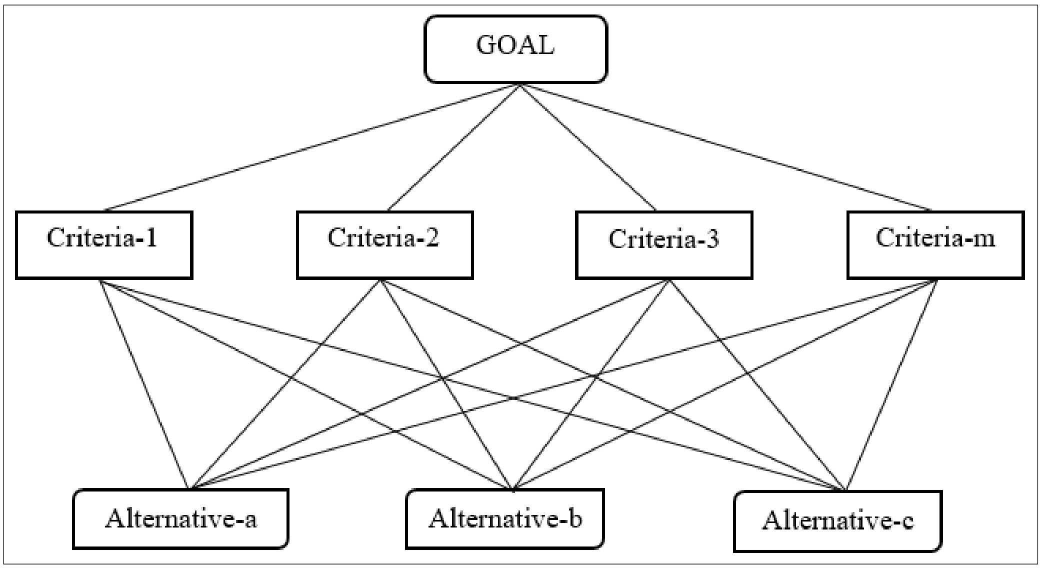

Figure 2.7: Generic hierarchy structure of AHP.

Within the AHP technique, we perform the pairwise comparison between the related elements and obtain the weight for each element. The total weight of elements which are gained from the pairwise comparison matrix must be 1. Moreover, it's possible to determine the consistency of the pairwise comparison matrix in the AHP method by the Consistency Ratio (CR). The value of the CR can be compared with the value of the Random Index (RI). Figure 2.8 shows the flowchart of the AHP method [47].

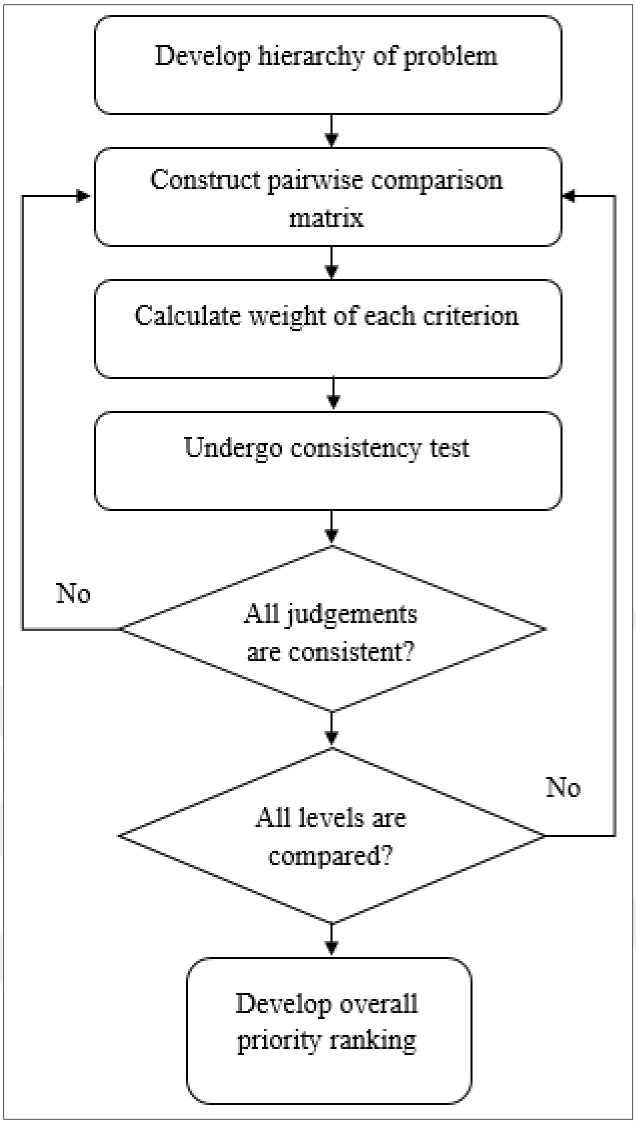

Figure 2.8: Flowchart of the AHP.

AHP method can be described in three steps as following [48] and [49]; Generating the pairwise comparison matrix, Computation of criteria weights , and Evaluation of consistency ratio.

The mentioned steps above have been implemented for finding the weights of criteria and the results were integrated with the GIS technique to determine parking demand and consequently, the parking demand map was prepared.

A. Generating the pairwise comparison matrix

In this step, we perform the pairwise comparison between the related components. Each component must be at the same level. In this paper, in order to conduct the pairwise comparison, a questionnaire survey has been designed and distributed among experts from ISPARK, IBB Istanbul directorate, and academician to obtain their opinions. The pairwise comparison performs on a qualitative scale and the scale range is from 1 to 9, where each number indicates the relative importance of criteria over another criterion [43]. The relative importance of criteria can be shown in Table 2.3.

Table 2.3: Relative importance of pair-wise comparison.

Value	Relative Importance
1	Equally important
3	Moderately important
5	Strongly important
7	Very strongly important
9	Extremely important
2,4,6 and 8	Intermediate judgments

B. Computation of criteria weights

This part compasses the following operations. Firstly, the sum of each column was calculated in the pairwise comparison matrix. Each was divided into the matrix by summation of its column and the result indicates the normalized pairwise comparison matrix. Then, the average of components was calculated in each row of the normalized matrix. The results provide the weight of the criteria.

C. Evaluation of consistency ratio

In this section, the CR of the n elements is being estimated in order to assure whether the judgment is consistent or not. If the CR does not reach the required level then the pairwise comparison may be revised [50]. The bellow formula calculates the (CR):

$$CR = \frac{CI}{RI} \tag{2.1}$$

In the above equation, CI is a consistency index that is derived from equation 2.2 and RI is a random index that is acquired through Table 2.4 for several numbers of variables (n) [8].

$$CI = \frac{\lambda_{max} - \text{n}}{n-1} \quad (2.2)$$

Where λ_{max} is the maximum eigenvalue of the pair-wise comparison matrix.

Table 2.4: Values of Random Index.

n	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RI	*0*	*0*	*0.58*	*0.9*	*1.12*	*1.24*	*1.32*	*1.41*	*1.45*	*1.49*

The concept of the CR is designed in a way that if $CR \leq 0.10$ the ratio expresses the validation of consistency in the pairwise comparisons; if $CR > 0.10$ then the ratio values are inconsistent, it requires reconsideration of pairwise comparison matrix [13].

2.4. Location-Allocation as Network Analyst Technique

The most significant factor that leads a private or public organization into success is often referred to as the best location. A private-sector organization can get benefits from a good location, whether a small coffee shop or a worldwide chain of retail outlets. The location can support the low costs to remain fixed and the accessibility remain high. If a good location is chosen for public-sector services, such as hospitals, libraries, fire stations, schools, and emergency response services (ERS) centers, they will supply high-quality service to the society at a low price [51].

The location-allocation issue was started from Weber's location-allocation problem in 1909, and still, it is under investigation. The purpose of location-allocation is to specify the optimum locations for facilities in such a way that the demand points were distributed. It minimizes the total weighed distance or time in terms of demand locations and weights [52]. The location-allocation problem as the name itself said, has a twofold problem that locates the facility and allocates the demands to the facilities at the same time.

ArcGIS software also contains the location-allocation analysis in the extension of network analyst which is able to implement the location-allocation problem. The location-allocation analysis in ArcGIS software presents six distinct types of problems that respond to the specific kinds of questions. These problem types are; minimize impedance, maximize coverage, minimize facilities, maximize attendance, maximize market share and target market share [51].

The minimize impedance and the maximize coverage problem types have more usages and mostly used methods than any other problem types in the sectors and works in literature. The objective of minimize impedance is to minimize the distance from demand to the facility. It is used to reduce the distance or driving time from facility to demand and the result is the low-cost transportations. This problem type is used to locate the facilities such as warehouse, airport, libraries, car parking areas, etc. The maximize coverage problem type is used in such cases when you want to cover maximum demands or wish to cover 100% demands. This problem type is used to specify the location of emergency rescue centers like fire station location, police station location, and etc. [6].

The location-allocation problem has three basic components; facility, demand, and network area. The role of the mentioned components may vary in different location-allocation problems.

Facility: In the location-allocation problem, the term of the facility is used to describe an object in which the geographic position of this object is optimized by algorithm or model considering the interaction with other pre-existing objects. Hospital, school, parking lots, an outlet of chain-store, warehouses etc., these objects are examples of facilities. The facility has some properties like the number, type, costs etc. [53].

One of the properties of the facility in the location-allocation model is referred to as the number of new facilities that need to be set up in the study area. Inside the location-allocation model, single facility or multi facilities can be established. Thus, establishing a single facility considering the existing facility inside the location-allocation model is a pretty simple example. Establishing the multi-facilities which are locating two or more than two facilities at the same time are more common inside the location-allocation model [54].

Other significant properties of the facility are type and costs. The facility type comprises the service of the facility and the capacity of the facility, and the cost facility includes fixed cost and variable cost.

Demand: Demand is an important component of the location-allocation model which is also called customer [55]. A customer or a demand is a person who needs accessibility to a service or to a supply of a good [53].

Network space: The third important component of the location-allocation model is network space that is a base data set for road network which is computing the distance and driving time between facilities and demands.

We discussed the essential components of the location-allocation problem. The common models of the location-allocation problem will be explained in the next sub section.

2.4.1. P-median Model (Minimize Impedance)

The P median model is one of the simplest, most common and most studied methods in the location-allocation model. This model recognizes the median points amongst the potential points in order to minimize the total cost from the objective functions. One of the main goals of the P median problem is to minimize the total weighted distance and the time consuming between facility and demand locations [56]. It is expected that demand does not consider the capacity in this model, it prefers to get benefit from the closest facility. If p equal to 4 (P=4), the p median means; 4-median problems. Afterward, the model searches locations of 4 facilities. The public type facility mostly includes in this problem such as school, hospital, parking lots, ambulance, firefighting etc. [53].

The P-median model can be defined with a maximum distance constraint. For instance, a parking facility must not far from demand locations with maximum distance constraints (d_{max} = 500m) to identify a different subset of facilities in each demand. The objective function of the P-median model can be specified as Formula (2.3) [55];

$$Minimize\ Z = \sum_{i \in I} \sum_{j \in J} a_i d_{ij} x_{ij} \quad (2.3)$$

- $Z =$ objective fucntion;
- $I =$ all the demand locations on the network;
- $J =$ all the condidate facility locations on the network;
- $a_i =$ the number of demands at the demand location i;
- $d_{ij} =$ the distance from candidate facility j to demand i
- $p =$ the number of facilites that need to be located;
- $d_{max} =$ maximum distance constraint;

The total demand from a separate demand location is given as:

- $x_{ij} = (0,1)$ for all (i, j) is allocated to only one facility, where:
- $(d_{ij} \leq d_{max}) \Longrightarrow 1\ and\ (d_{ij} > d_{max}) \Longrightarrow 0$

Given the following constraints;

- A facility has to be allocated with a separate demand site: $x_{ij} \leq x_{jj}$ for all (i, j)
- An open facility must be allocated a demand: $\sum_{j \in J} x_{ij} = 1$ for all i
- Only the p facilities are to be located: $\sum_{j \in J} x_{jj} = p$ for all j
- The sum of them equals the number of facilities to be located.

2.4.2. Minimize Facilities Model

This model minimizes the number of facilities that cover all demands within a distance constraint or travel time [57]. Minimize Facilities Model is similar to the Maximum Coverage Model in terms of allocating demand points but Minimize Facilities have the exception of determining the number of facilities to locate [58]. The minimize facilities model can be specified as Formula (2.4);

$$Minimize\ Z = \sum_{j \in J} x_j \qquad (2.4)$$

Where:

- Z = objective fucntion;
- I = all the demand locations on the network;
- J = all the condidate facility locations on the network;

x_j takes the value 1 in a situation where a facility is opened at candidate location j, otherwise, its value still be 0.

The range of demands has to be either a maximum service distance or the time to at least one open facility location.

$$\sum_{j \in N_i} x_j \geq 1 \; for \; all \; i \quad (2.5)$$

A candidate facility location has to be closed or open: $x_j(0,1)$ $for\ all\ j$

N_i the collection of facilities when the distance between demand location i and candidate facility j is less than the critical distance or time, or $d_{ij} \leq s$;

- d_{ij} = the distance from candidate facility j to demand i
- s = the symbol of important service distance or time.

2.4.3. Maximize Coverage Model

The Maximize Coverage Model is considered as another type of location-allocation problem. This problem intends to maximize coverage for the number of demand points within a specified distance or travel time. In another word, this model seeks to cover all demands with the minimum number of facilities within a distance constraint or travel time. In this model, in order to reach their target, the facilities intend to cover maximum demands [59].

The implementation of this model is suitable for those services which have multiple facilities as a network. This model is suitable where accessibility is an essential factor for market share and profit. For instance, this model can be used for establishing the wireless tower for the network, setting the siren alarm for an emergency, chain store, and multiple outlets. The difference between the P-median and Maximize Coverage model is in covering demands. The P-median model must cover all demands but the Maximize Coverage Model may or may not cover all demands [60].

The function of Maximize Coverage as written by Murawski & Charch [59] can be described in the following Formulas;

$$Minimize \; Z = \sum_{i \in I} a_i y_i \quad (2.6)$$

$$\sum_{j \in N_i} x_j + y_i \geq 1 \;\; for \; all \; i \in I \quad (2.7)$$

$$\sum_{j \in J} x_j = p \qquad (2.8)$$

- $x_j = 1$ when the facility is assigned to the j, otherwise $x_j = 0$
- $y_i = 1$ when demand is fulfilled at the i, otherwise $y_i = 0$
- $Z =$ objective fucntion;
- $I =$ all the demand locations;
- $J =$ all the candidate facility locations;
- $a_i =$ specifies the demands at the demand location i;
- $N_j = (0,1)$ for all $j \in J \quad y_i = (0,1)$ for all $i \in I$
- $N_i = \{j \in J \,/\, d_{ij} \leq d_{max}\}$;
- $p =$ the number of facilites that need to be located;
- *S* signifies the distance; when it is past the demand point it is thought to be uncovered. (the value of *S* is selected as your choice for each demand point).

2.4.4. Maximize Attendance Model

This model aims to maximize the attendance of the demands to the facilities within a certain distance or travel time. It relatively allocated to facilities that are close to the majority of demand. Thus, demand points with high demand weight will be allocated in priority. It does not aim to provide complete coverage to demand point, indeed it allocates a ratio of the demand weight for each demand point. This characteristic is the main difference between the Maximize Attendance Model and other models [7].

In addition, some models as used in ESRI network analysts can define the number of maximum attendances for each facility.

The objective function of the Maximum Attendance Model was defined by Holmes et al in 1972 [61] and can be seen as Formula (2.9);

$$z = \sum_{i=0}^{n} \sum_{j=0}^{n} a_i (S - d_{ij}) x_{ij} \qquad (2.9)$$

The demand in the *i*th location, then i=1, 2, …n is usually symbolized as the total number of demands;

- $d_{ij,}\ j = 1,2, \dots n,$ specifies the distance between locations i and $j,$ an appropriate metric is required to measure it;
- S signifies the threshold distance; in this study $d_{ij} \leq d_{max}$

The variables used to make choices are as follows:

- $x_{ij} = 0$ when the location *i* is not attended by a facility in *j;*
- $0 < d_{ij} \leq 1$ when the location *i* is attended by a facility in *j*.

3. PARKING DEMAND BY THE INTEGRATION OF GIS AND AHP

The recent technological advancement and sophistication have led to increased urbanization, with more people moving to urban areas. The increased number of people has characteristically negatively impacted urban transportation systems through a rapid increase in vehicle numbers. Therefore, most of the large and developed cities suffer from lack of parking areas. Parking areas play an important role in modern urban transportation and traffic management system. Efficient parking areas decrease traffic load and reduce marginal parking, hence, indirectly increasing street widths and improving the motion of vehicles. Accurate location of the parking area is the main issue in traffic management, and wrong decisions can cause inefficient traffic management, urban transportation system, economic loss and increases environmental degradation [1].

A region with residential, business or commercial activities usually requires parking areas. Supplying sufficient parking areas to meet parking demands in such regions may rectify marginal parking [2].

Determining parking demand is directly related to disparate parameters and their relative importance. Selecting parking areas using a traditional way cannot give us reliable results, since it considers very few parameters like land price. Thus, it's essential to develop an approach that considers all the effective parameters simultaneously. One of the successful methods is the integration of GIS with AHP. GIS is widely recognized for its capabilities in performing geographic analysis and is designed to manipulate the efficiency of geographical positioning [14]. AHP, on the other hand, allows personal judgments in a reliable way, easy to understand, and does not require complex mathematics. The GIS-AHP approach allows for the study of complex problems and provides sufficient results to decision-makers. According to these considerations, this section of the dissertation deals with the GIS-AHP method for delineating parking areas to meet demand in Pendik district.

3.1. Analysis Procedure

During the analysis procedure, all stages of geographic analysis were performed by ESRI ArcGIS version 10.3 software. The reason that we selected this software is the capabilities of performing analysis on vector data and raster data. Apart from basic GIS analysis tools, it has the capabilities of creating geodatabase, processing geographic data, geographic visualization, editing, manipulating and reporting. Figure 3.1 shows ArcGIS spatial analyst tools.

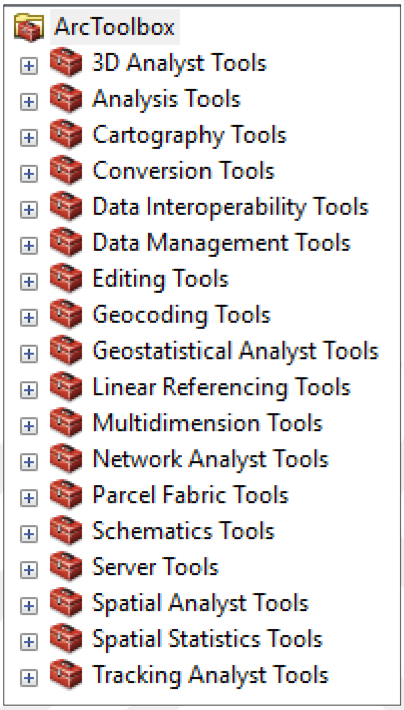

Figure 3.1: Spatial analysis Arc Toolboxes.

Considering the headings of criteria, all adopted data were classified and recorded in the geographical geodatabase (gdb). All the adopted data were geo-referenced and registered to ITRF 96 coordinate system to ensure that the study area was maintained, and no distortion happens during analysis which can direct to imprecise results. All data were provided in a vector format, except the slope of the area, which was derived from the digital elevation model (DEM) in a raster format.

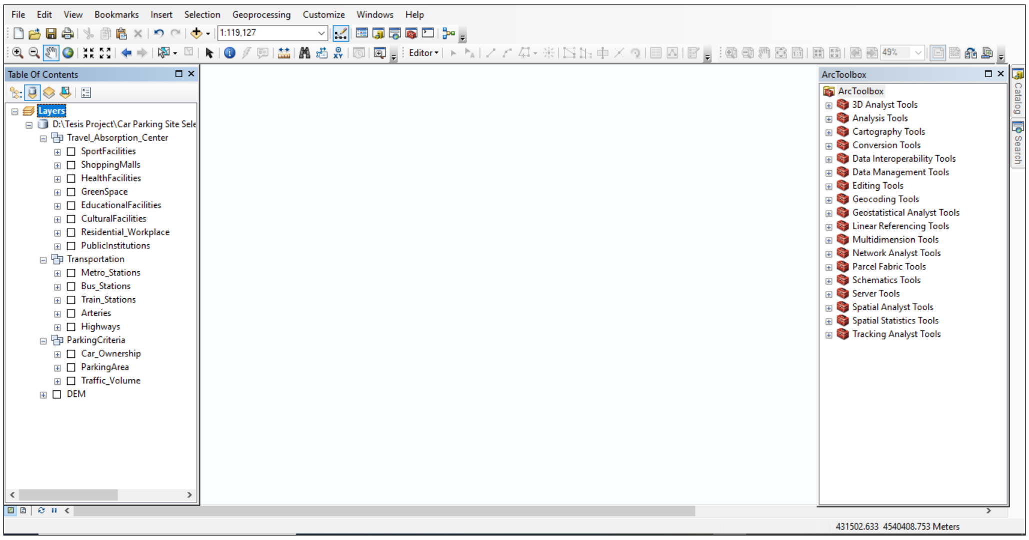

Figure 3.2: ArcMap screen.

Data representation and data analysis were done in the ArcMap of ArcGIS software. “ArcMap is the primary application used in ArcGIS and is used to perform a wide range of common GIS tasks as well as specialized, user-specific tasks” [33] by means of this application or interface we directed the data from geodatabase and made ready for performing geographic analysis (Figure 3.2).

3.2. The Study Area

Pendik district of Istanbul was chosen as a case study area for this research. The study area was found to be suitable for the experimental study in terms of quality, quantity, legibility, and distribution of data. Figure 3.3 displays Pendik district, surrounded by Tuzla from the east, from the west by Kartal and Sultanbeyli, from the north by Sile and from the south by Marmara Sea. Pendik, with an area of 190 km^2, has a coastline of 7.5 km.

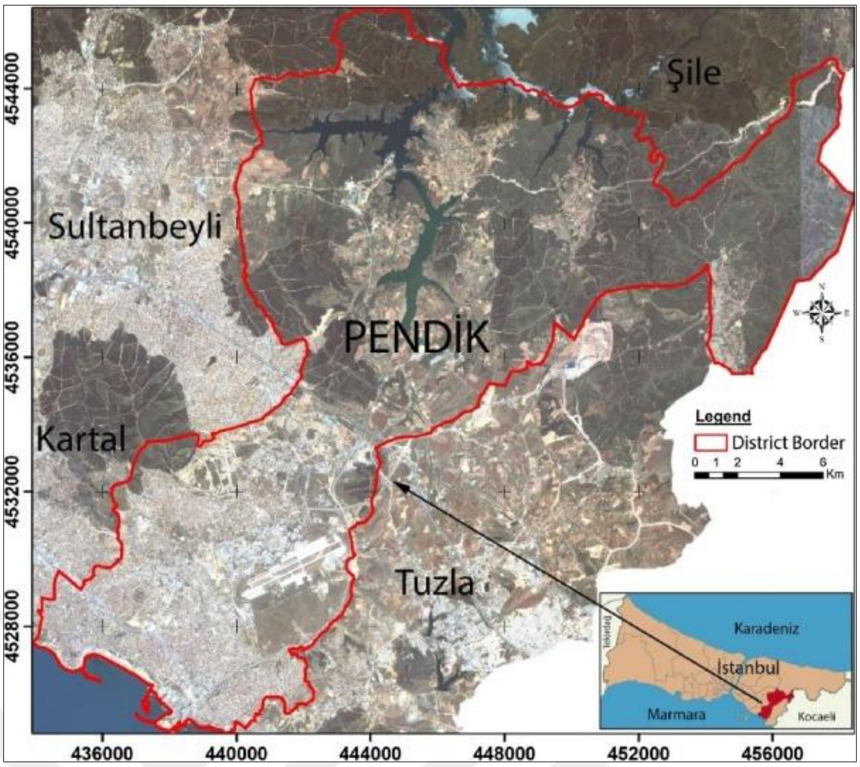

Figure 3.3: Map of the study area.

In recent years, Pendik district has rapidly developed in both transportation infrastructure and urbanization. Railway system investments, road investments, highway investments, and access to the sea are noteworthy in the region. Due to these reasons, it makes the city an attractive center and the city is also faced with a lack of several city services, one of them is parking areas.

3.3. Methodology

The methodology implemented in this study can be explained in Figure 3.4.

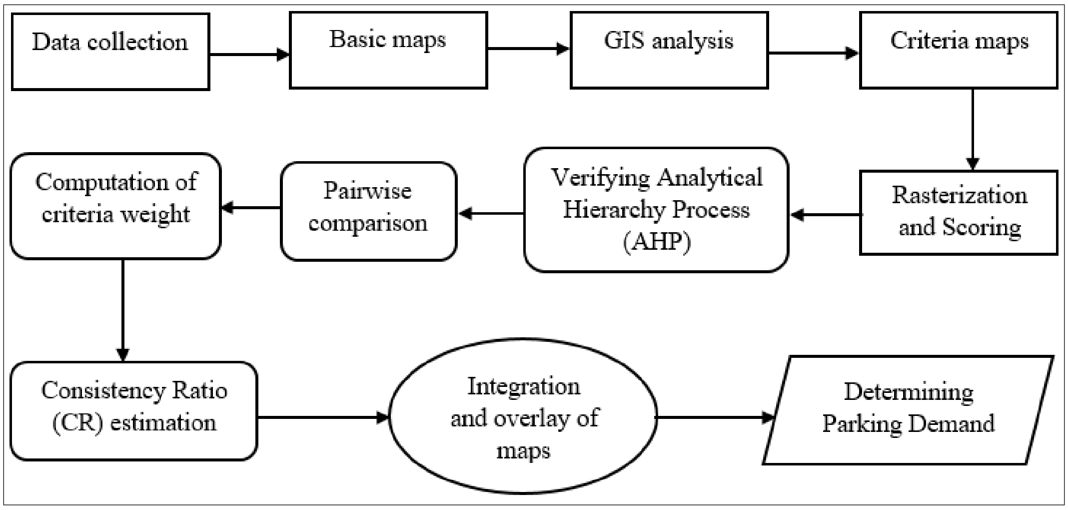

Figure 3.4: Flow of methodology.

This methodology carries out in three stages. In the first stage, the data was collected and directed to ArcGIS software and create the basic maps. Afterwards, geographic analysis was performed, and rasterization and scoring also done in the procedure. In the second stage, weight of the data was calculated using AHP method and the consistency ratio also computed by Equation 2.1. in the third stage, the weight of data was assigned, and data were overlaid to determine the suitable parking places.

To specify the areas to be selected as parking lots, all criteria which affect the physical, legal and geographical suitability for parking areas have been determined. For optimal use of this approach, it is necessary to apportion the criteria into groups. Accordingly, for the implementation of the MCDM method, the criteria are divided into sub-criteria. Moreover, it's useful to weight the data at the level of criteria and sub-criteria during the implementation of the MCDM technique. Considering literature reviews, experts' opinions and availability of data, all criteria were grouped under three main classes:

- Transportation criteria
- Parking criteria
- Travel absorption centers

The criteria were divided into sub-criteria according to their characteristics, Figure 3.5 illustrates the hierarchy of criteria and sub-criteria for determining parking areas.

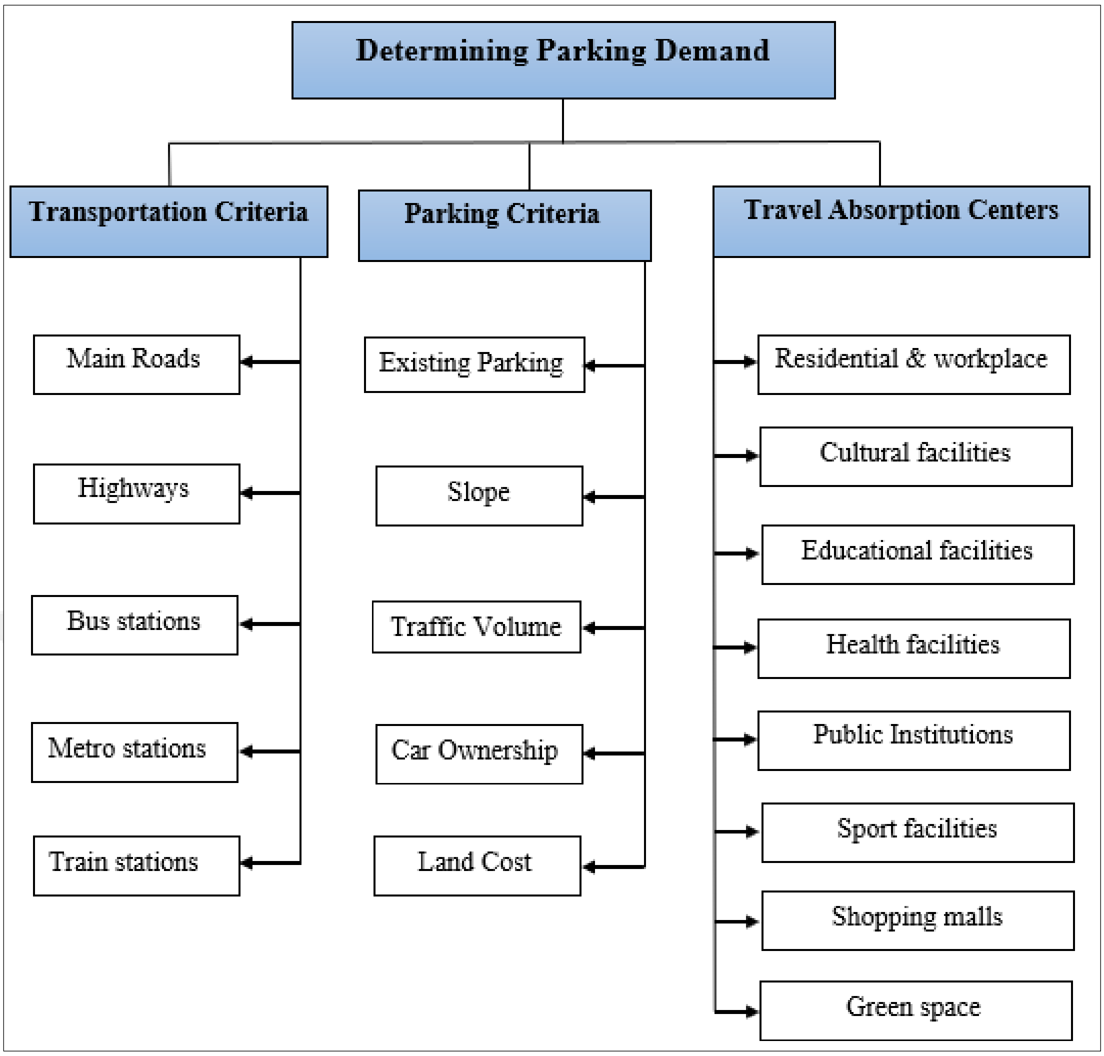

Figure 3.5: Hierarchy of criteria and sub-criteria.

All data were provided in a vector format, except the slope of the area, which was derived from the digital elevation model (DEM) in a raster format. In this study, different geographic analysis techniques of ArcGIS were applied according to the purpose of use. As a result of these analyses, all layers were converted to raster format in order to produce the result layer. The walking distance to parking places from the transportation criteria and Travel Absorption Centers (TAC) is one of the most considerable issues which is considered in this study.

For further analysis, the criteria maps were rasterized and scored because computation in raster data is not as complicated as vector data [62]. The scoring process was done by the reclassifying tool, with the rasterized being classified into 5 values. Scoring the distance for transportation criteria and TAC was considered based on the accessibility to parking areas, which means that minimum distance has the maximum values. To be nearer the parking area from the transportation and

TAC criteria, it is better for the user to park their vehicles. Regarding the slope, the maximum values of the slope have the minimum scoring value.

The AHP method was used to calculate the weights of criteria and their sub-criteria. The values used to compare the relative importance of each parameter can be seen in Table 2.3. Afterward, the classified maps were integrated into the raster calculator tool and multiplied by their weightages in order to obtain the suitability map of parking areas.

3.4. Transportation Criteria

Transportation is one of the most significant factors for parking area because transportation attracts more travelers than other criteria. Selecting parking locations near transportation terminals such as bus stations, train stations and metro stations, which attract and absorb a massive group of travelers, are increased the sufficiency of parking. The distance from transportation is also a subject of issue. The distance should be in such a way that the passengers, employees, and users reach their target from a parking spot with minimum walking distance. In this study after consulting with academician experts, 1km is the maximum acceptable distance.

3.4.1. Arteries (Main Roads)

Arteries generally transfer majority of the travels in and out of the urban area with continuous movements passing through the city center. Moreover, main roads also serve the trips between central business areas, surrounding residential places, and serves passage between urban settlements. Depending on the geographic distribution of arteries, the number of vehicles also increases in the study area.

The walking distance from arteries to parking areas is the most considerable issues. We applied the Euclidean distance technique on arteries data to calculate the walking distance. We created a distance of up to 1000 m. Afterward, we reclassified the distance into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5 as shows in Figure 3.6.

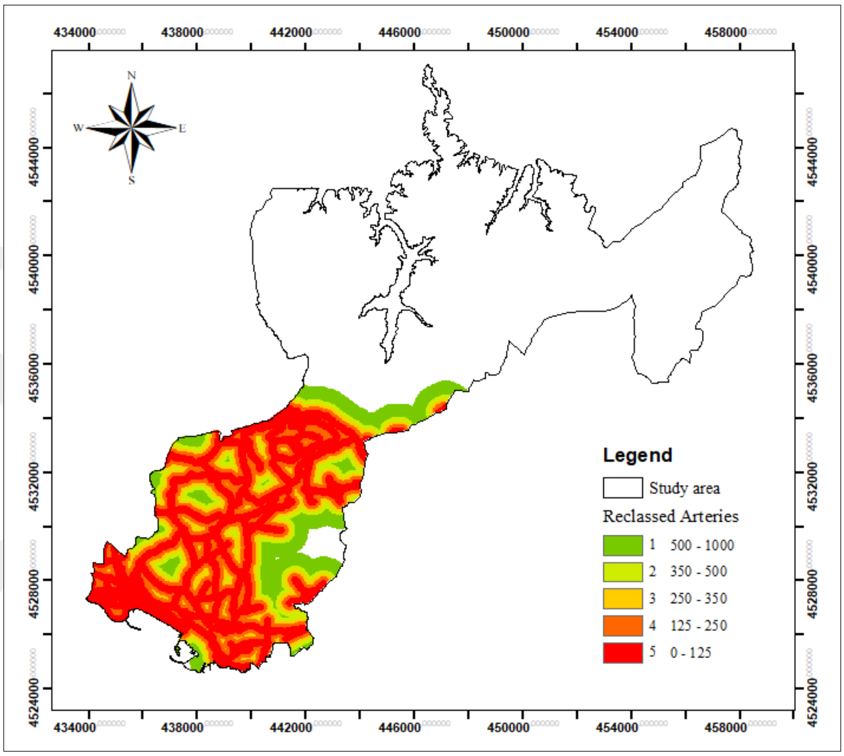

Figure 3.6: Reclassified arteries distance.

3.4.2. Highway

The main public road is a highway which connects different cities, towns, villages etc. to each other. It plays a significant role in developing the economy of a country. A good highway network reduces heavy traffic, enhances transport systems, decreases transportation costs and makes travels easier, safer and faster. There are two highways that cross from Pendik district; one is D-100 highway of Istanbul-Ankara and another is European E-way E-80. The D-100 highway starts from the Edirne city and ends at the Ağrı city, the length of this highway is 1842 km, 8 km of which is inside the Pendik district [63]. The E-80 highway is an international highway that starts from Lisbon of Portugal and ends at the Gürbulak border crossing at the entrance to Iran. The length of this international highway is

5600 km, 71 km of which is crossing from Istanbul and almost 3 km is inside the Pendik district [64].

We applied the Euclidean distance technique on highways data to calculate the walking distance. We created a distance up to 1000 m and classified the highway distance into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000 m, and giving each range a discrete integer value between 1 and 5 as seen in Figure 3.7.

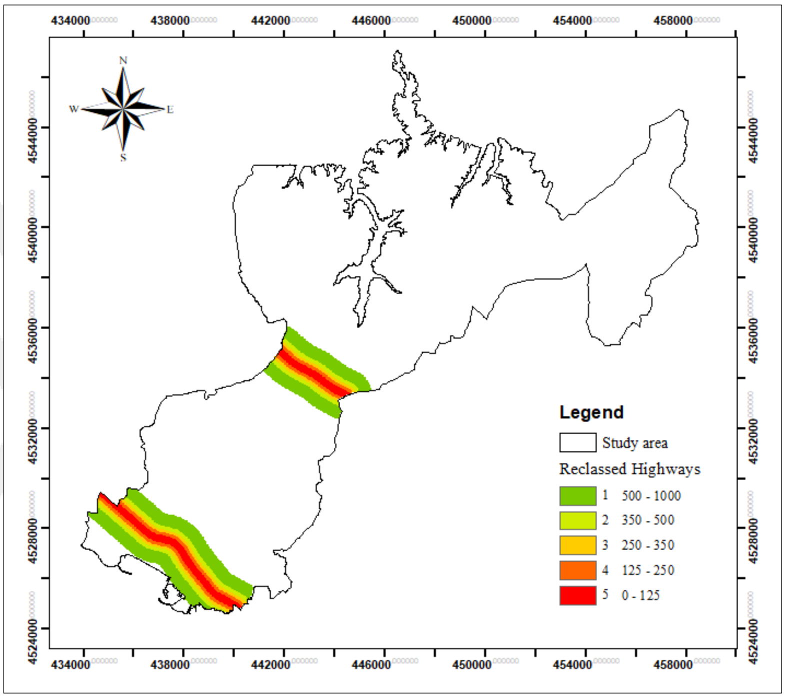

Figure 3.7: Reclassified highways distance.

3.4.3. Bus Stations

The bus is a public transportation system that is designed to carry many passengers across the city. The capacity of this public transport can be as high as 300 passengers, it's convenient, comfortable and low cost of the public transport system [65]. A bus station is a place in the city or intercity where bus stops pick up and drop off the travelers. Therefore, the parking area should not be far from the bus stations.

We applied the Euclidean distance technique on bus station data to calculate the walking distance. We created a distance layer of up to 1000 m and classified the distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and

500-1000 m, and giving each range a discrete integer value between 1 and 5, as shown in Figure 3.8.

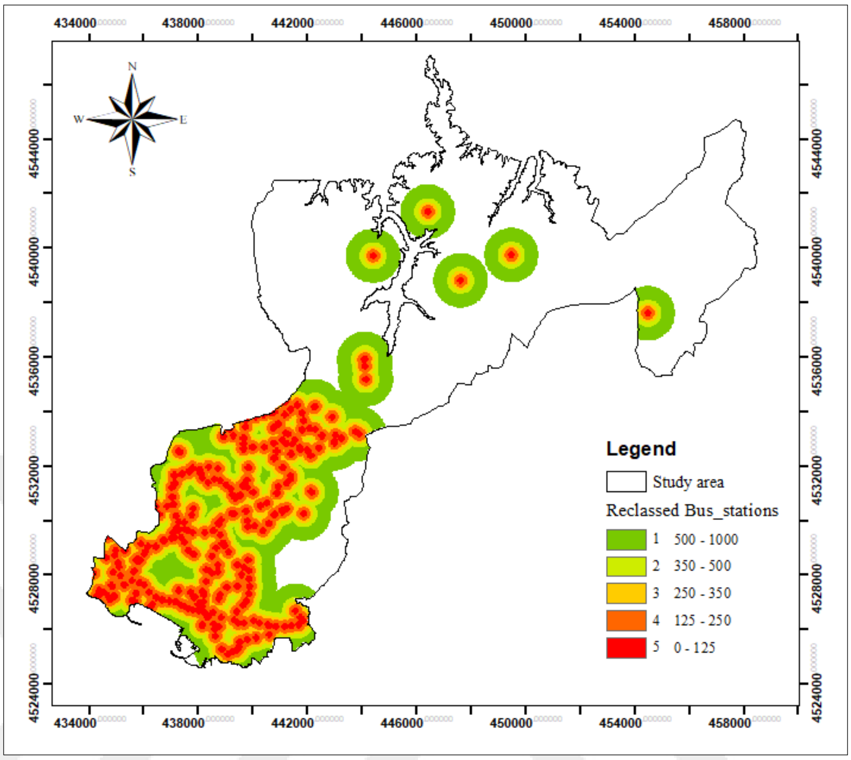

Figure 3.8: Reclassified bus stations distance.

3.4.4. Train Stations

The train is a transportation system comprising of a series of connected trucks that generally runs along the railway carrying cargo or groups of passengers and it's a fast transport facility. The train station is a railroad facility where trains routinely stop to load or unload the cargo, or pick up or get off the passengers [66]. The P & R facility is usually created near to the train station, where passengers park their vehicles and use the train facility to inter the city. Therefore, this parking facility has the function of reducing traffic congestion in city centers.

Considering our data, there are four train stations located in Pendik district, these stations are Kaynarca, Tersane, Güzelyalı, and Pendik. By applying the Euclidean distance technique, 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m walking distance was created, and reclassified these distances into ranges value and giving each range a discrete integer value between 1 and 5, as illustrated in Figure 3.9.

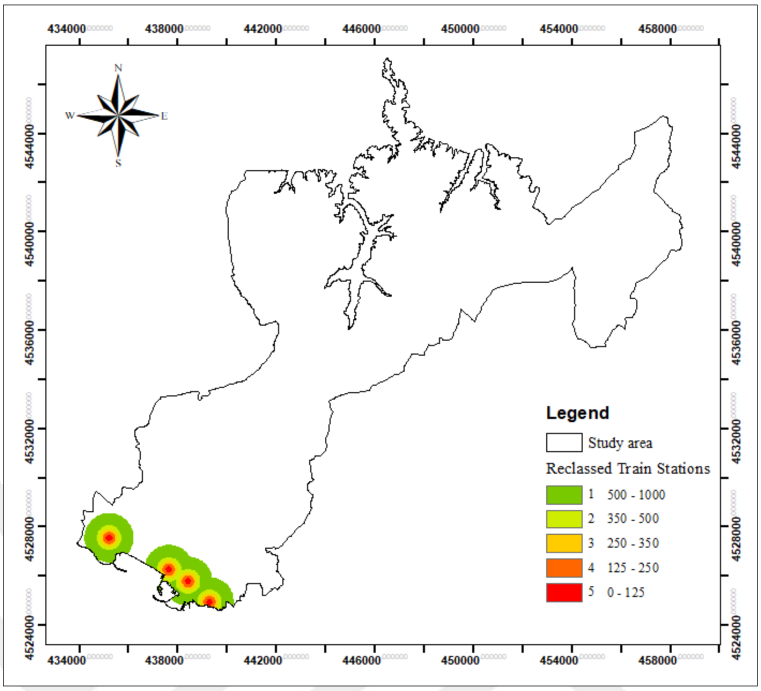

Figure 3.9: Reclassified train stations distance.

3.4.5. Metro Stations

Metro is a high capacity public transportation system, also known as subway or underground, which was designed to transport passengers speedily. This rapid transit system generally created in urban areas. A metro station is a place that metro stop or load and unload the passengers. The location of metro stations is planned very carefully, in order to provide easy access to urban facilities like roads, major buildings, commercial centers and other transport hubs [67].

Considering the data, there are about 8 metro stations located in the Pendik district. We applied the Euclidean distance technique on metro station data to calculate the walking distance. We created a distance layer of up to 1000m and classified the distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5, as presented in Figure 3.10.

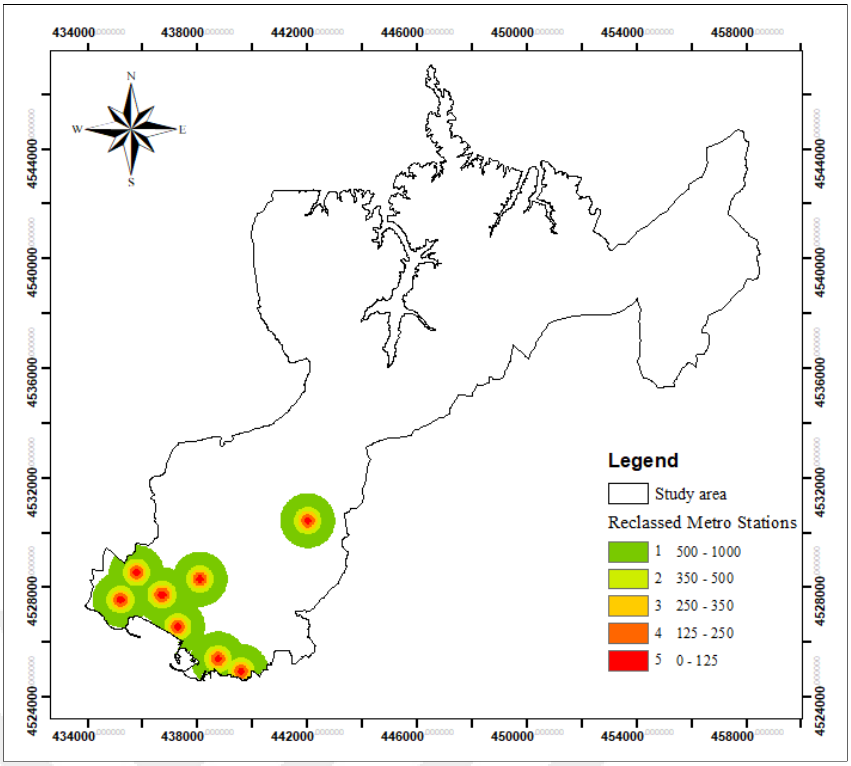

Figure 3.10: Reclassified metro stations distance.

3.5. Parking Criteria

Factors that are considered under this criterion include existing parking, slope, traffic volume, and car ownership. In this criterion, a limitation factor, such as existing parking, is also included.

3.5.1. Existing Parking

The current parking situation consists of parking lots that are operated by private sectors or public institutions. Considering the data, there are high-capacity parking lots where the traffic density is also high. This density also provides the necessity of parking facilities. Due to the increase in vehicle numbers, the location and capacity of these parking lots cannot maintain the need for parking in the city.

We applied the Euclidean distance technique on existing parking data to calculate the walking distance. We created a distance layer of up to 1000 m and classified the distance layer into 5 ranges; 0-125 m, 125-250 m, 250-350 m, 350-500 m, and 500-1000 m, and giving each range a discrete integer value between 1 and 5, as shown in Figure 3.11. The location of new parking areas should be far from the existing parking spots. Hence, the maximum distance has high value and the minimum distance has low value.

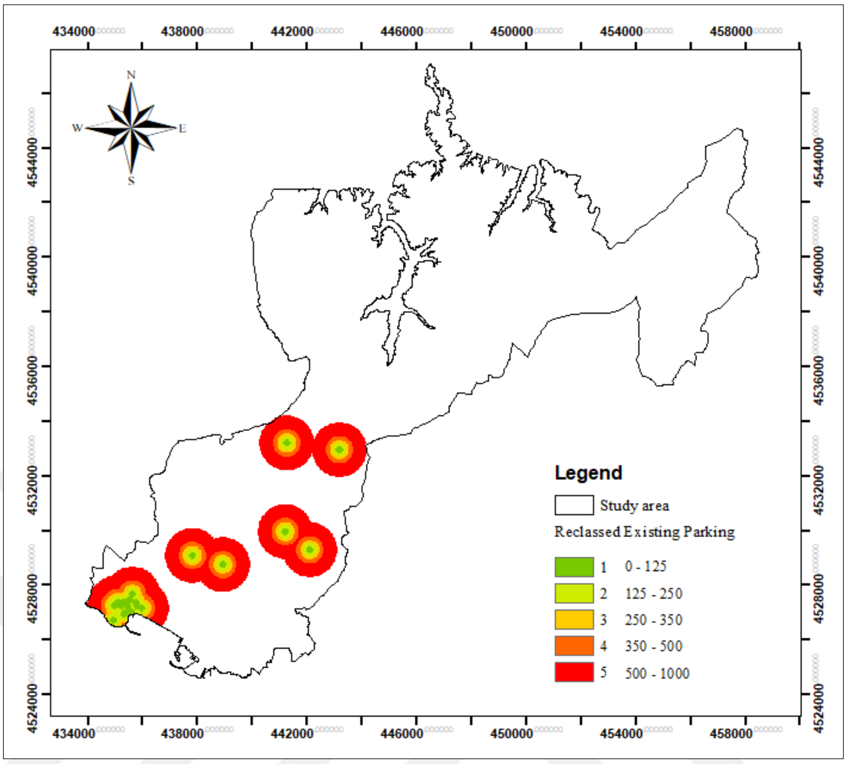

Figure 3.11: Reclassified existing parking distance.

3.5.2. Slope

Slope data for Pendik district was derived from the DEM. The slope data has an impact on accessibility and building a new parking spot. Thus, to build a parking spot we need to find areas of reasonably flat land. The slope values of the study area were produced from DEM, the values are from 0 to 39.56 degrees as the highest slope, and then the slope values were categorized according to the urban construction and land suitability evaluation into 0^o-5^o, 5^o-10^o, 10^o-15^o, 15^o-25^o and >25^o [68]. The categorized slope values were given a discrete integer value between 1 and 5, as illustrated in Figure 3.12. Regarding the slope data, the maximum values of the slope have the minimum integer value.

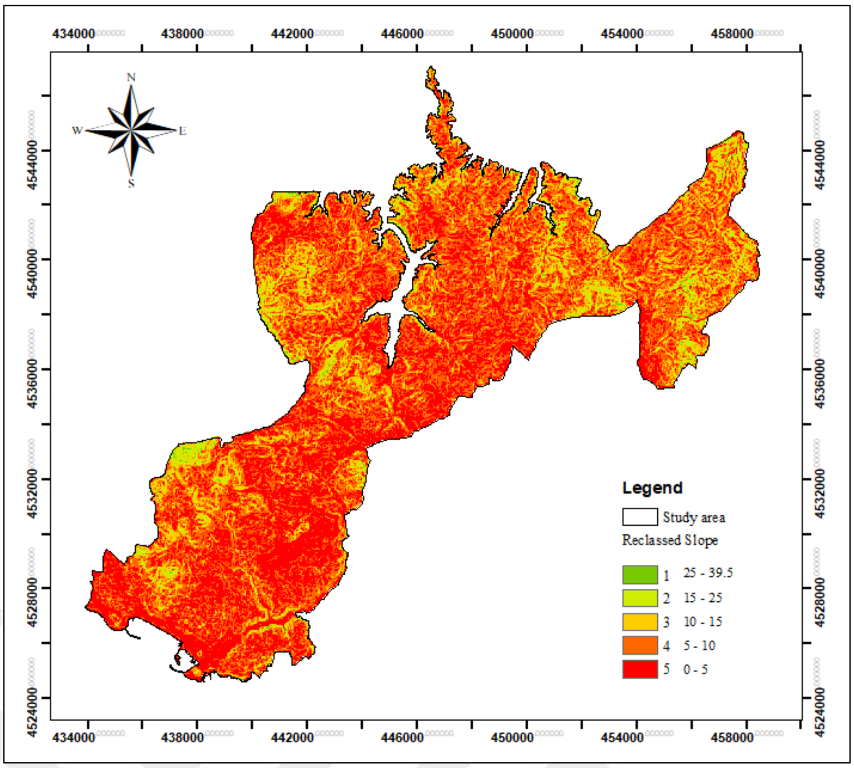

Figure 3.12: Reclassified slope of the area.

3.5.3. Traffic Volume

Traffic volume data are generally derived from the RTMS (Remote Traffic Microwave Sensor) that are placed on the main roads throughout Istanbul. RTMS is a radar technology used to detect vehicles with microwave signals. The RTMS can be used to measure vehicles and their average speed. RTMS reports the date, time spent, average speed of a vehicle and total volume values of each lane. Traffic volume values are the data that is normally generated in the vehicle/hour unit [69].

It has been accepted that the parking demand increases in places where vehicle mobility is at a high level, and where vehicle mobility is at a high level and the traffic volume is also high in those routes. In order to analyze the traffic volume data, the line density technique was applied according to road traffic volume values. Afterward, the result was reclassified and scored to produce the traffic volume layer as presented in Figure 3.13.

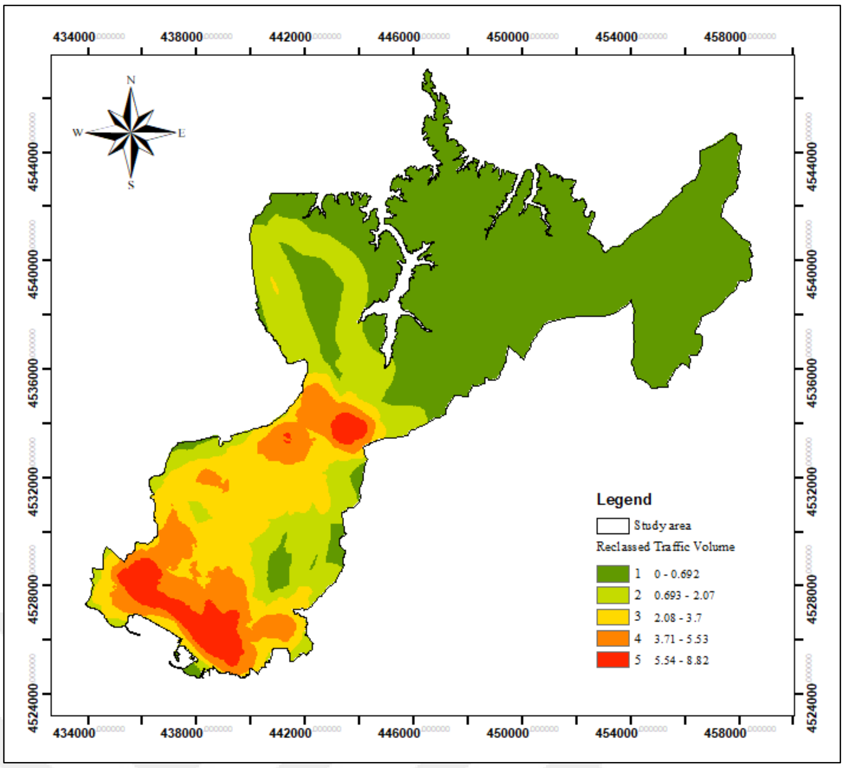

Figure 3.13: Reclassified traffic volume values.

3.5.4. Car Ownership

Car ownership can be presented as the number of vehicles per person. This ratio increases with the number of vehicles joining the traffic day by day. The increase in car ownership depends on many factors. These include increasing income, economic growth, diversity of needs, and inadequate public transport systems.

According to the data of Turkey Statistics Institution, the number of registered vehicles in Istanbul city was 23 086 900 by end of July 2019. In a period of January-July, about 220 976 number of vehicles have been increased in traffic [70]. Figure 3.14 illustrates the processed data on car ownership. The kernel density estimation technique was applied regarding the values of car ownership ratios to produce the car ownership layer. The resulting raster format that was reclassified gave a score between 1 and 5. The maximum value shows maximum car ownership.

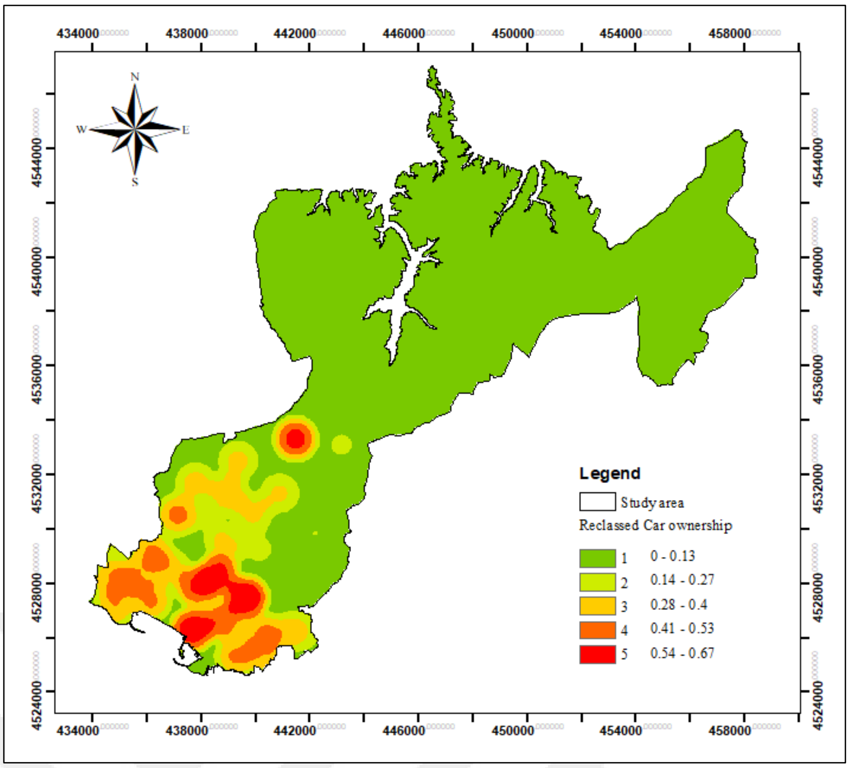

Figure 3.14: Reclassified car ownership.

3.5.5. Land Cost

Land price data consists of the buy and sale values of land at the neighborhood level. It is seen that the land prices are high in areas with high transportation facilities, close to business and public services, shopping centers, and modern urbanization. At the same time, parking demand is also high in these areas. Considering the transportation conditions and public interest, parking investment should be supported despite the high land cost.

Figure 3.15 shows the processed version of land cost data per area. Data were converted to raster data type regarding the land cost values. The resulting raster format was reclassified and gave a score between 1 and 5.

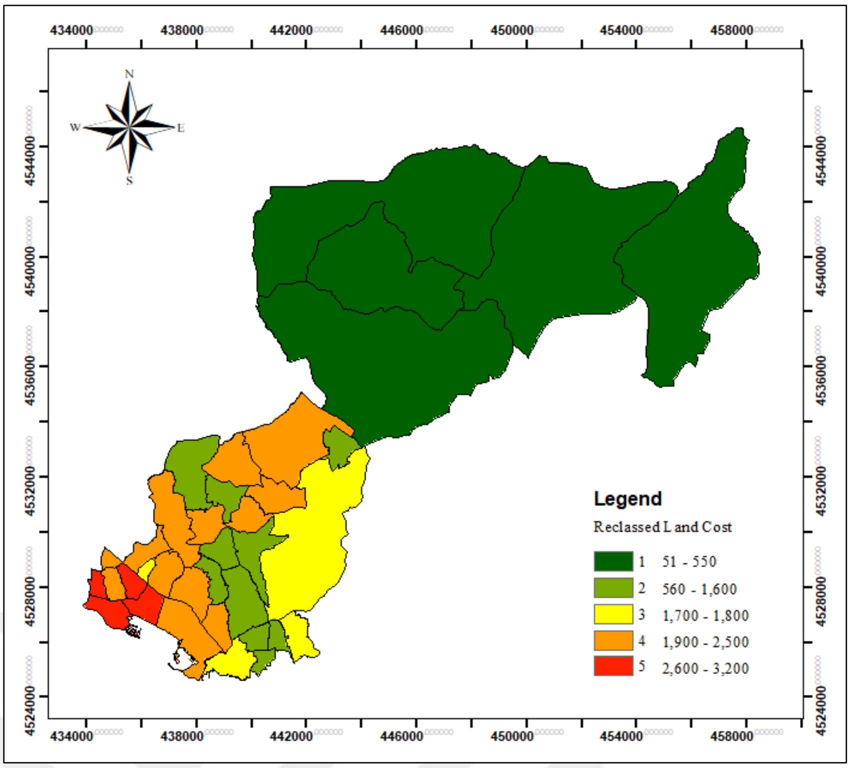

Figure 3.15: Reclassifie Land cost.

3.6. Travel Absorption Centers

TAC is a vital factor in determining the demand for parking area due to the increased frequency of absorbing travelers. The distance from the TAC is also a subject of issue. The distance should be in such a way that the passengers, employees, and clients reach their target from a parking spot with minimum walking distance. In this study, after consulting with experts, 1km is the maximum acceptable distance.

3.6.1. Residential and Workplaces

These data consists of polygons containing the number of independent houses and workplace units in the Pendik district. If public transportation facilities are low, people prefer private car and thus the number of vehicles increases. In recent years, the urbanization, rehabilitation and constructing buildings were also increased. Due to the lack of sufficient parking areas in residential places, people park their vehicles on sidewalks and roads. At the same time, a lack of parking areas causes traffic congestion in the region especially when cars make short pauses on the roads.

Figure 3.16 shows the processed version of residential and workplace layer data. The kernel density estimation was applied to the independent number of houses and workplaces in the buildings. The resulting raster format was reclassified and gave a score between 1 and 5. Maximum values present high density.

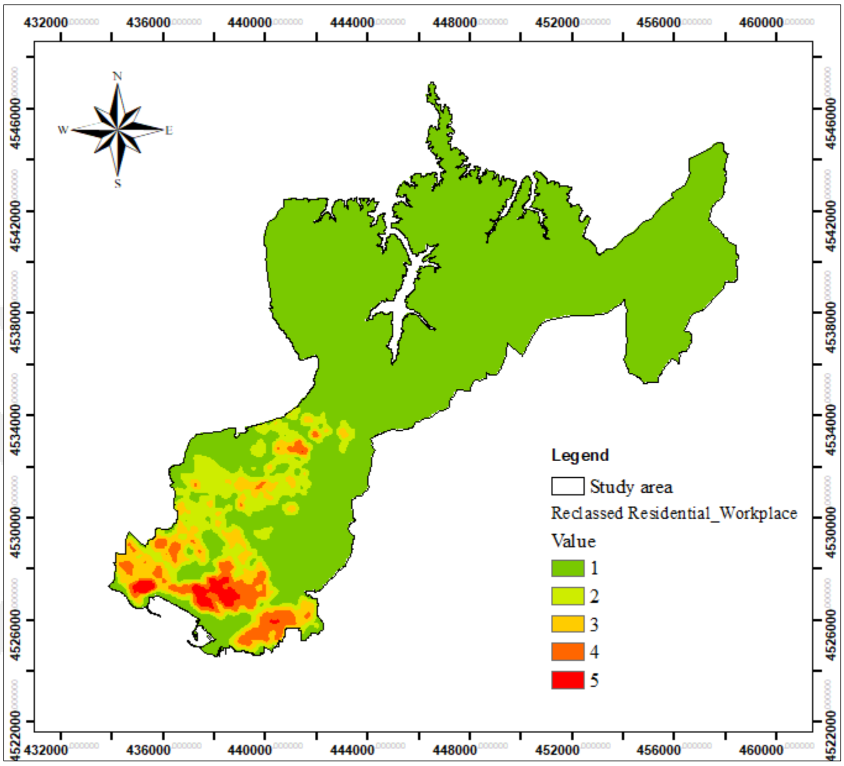

Figure 3.16: Reclassified residential and workplaces density.

3.6.2. Cultural Facilities

In the cultural facility data, you can find theaters, cinemas, libraries, shows and art centers, and art galleries. The facilities are mostly located in the south and southeast of Pendik district. These facilities open the whole day for different types of activities that are being held during the day. The reasons that parking areas are needed; refer to insufficient public transportation and participation in people in different kinds of organizations.

Figure 3.17 indicates the processed data of cultural facilities. The Euclidean distance technique was applied to calculate the walking distance from the cultural facilities. We created a distance layer of up to 1000 m, and classified distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5.

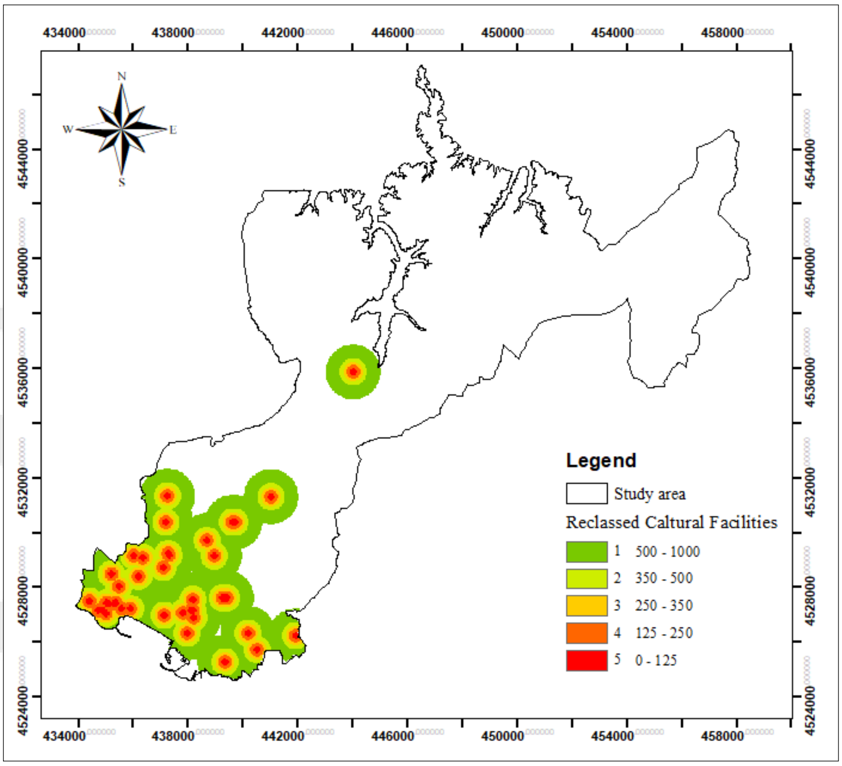

Figure 3.17: Reclassified cultural facilities distance.

3.6.3. Educational Facilities

Educational facilities data encompass primary schools, high schools, vocational high schools, private institutions, and kinder gardens. Using private schools and services is common for these facilities. Educational facilities almost distributed homogeneously around the study area only in the southeast the number is a little high. In educational facilities form the teachers and students increase the demand for off-street parking. some educational facilities located far from public transportations, therefore using private vehicles are common. Due to these reasons, the demand for parking areas increased.

Figure 3.18 illustrates the analyzed data on educational facilities. The Euclidean distance technique was applied to calculate the walking distance from the educational facilities. We created a distance layer of up to 1000m, and classified distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5.

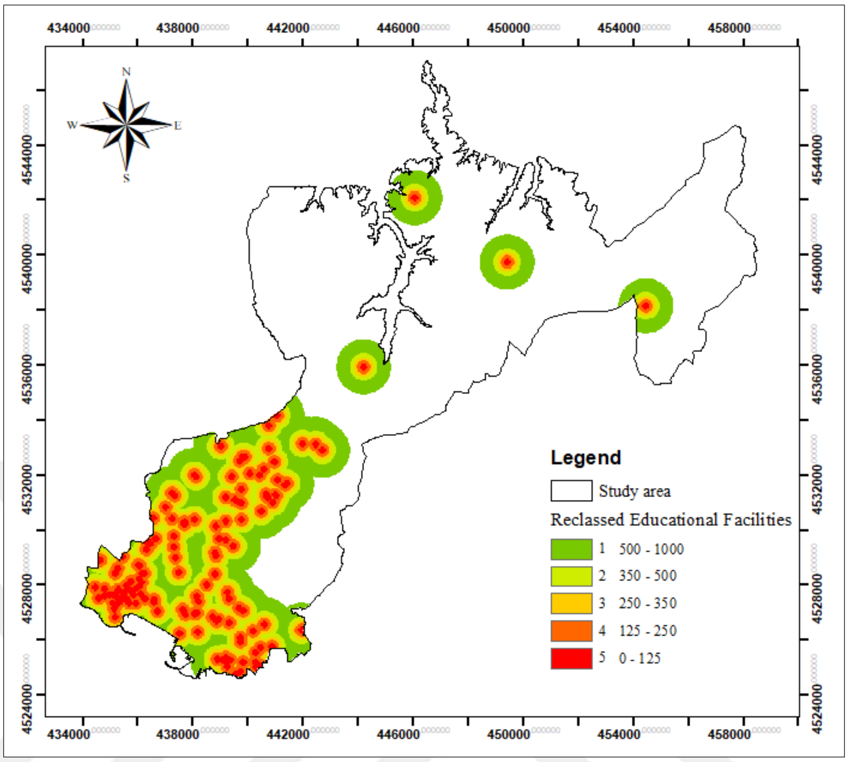

Figure 3.18: Reclassified educational facilities distance.

3.6.4. Health Facilities

Health facilities are, in common, any places where health care is provided. They include hospitals, healthcare centers, dispensaries, family healthcare centers, education and research hospitals, medical laboratory and research, polyclinics, and physical therapy. Health facilities, emergency facilities and logistical services should be provided without any problems. Most of the health facilities like hospitals are serving 24 hours and this facility includes their own personnel, patients and patient relatives. For these reasons, there is a need for parking areas.

Figure 3.19 shows the analyzed data on health facilities. The Euclidean distance technique was applied to calculate the walking distance from the health facilities. We created a distance layer of up to 1000m, and classified distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5.

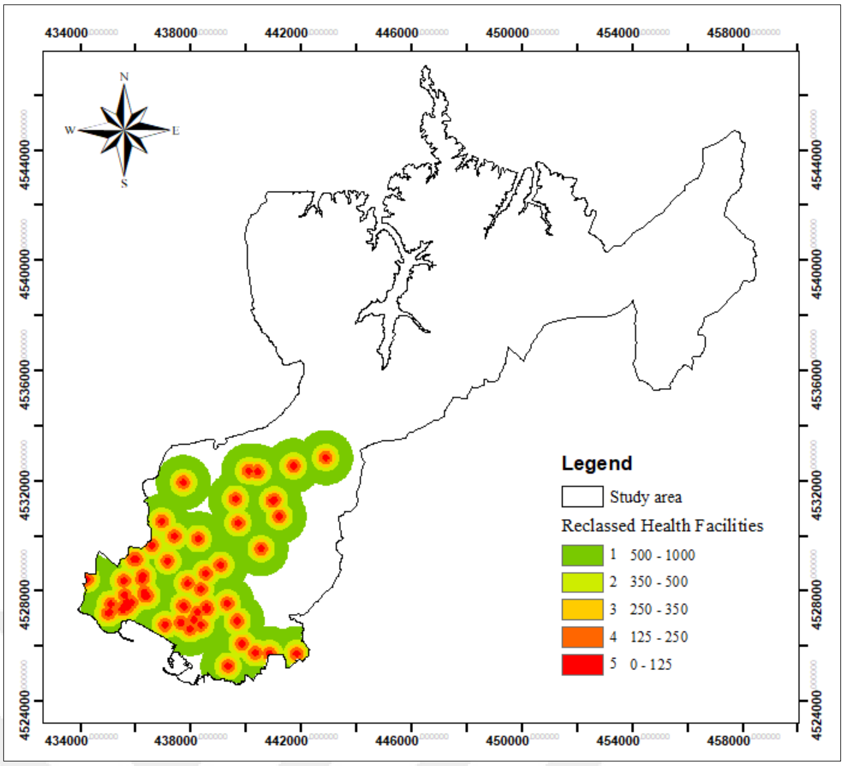

Figure 3.19: Reclassified health facilities distance.

3.6.5. Public Institution Facilities

Public institutions data contains social security centers, municipality, district police departments, post offices, prisons, police stations, neighborhood chieftainship and courthouses. These facilities attract intensive human activities, especially on weekdays. Generally, these facilities are located nearby arteries and in busy areas of the city, at the same time, these facilities are also high traffic attraction points. Due to inadequate parking areas, the personnel and the clients park their vehicles nearby the institutions and directly affect the traffic flow.

Figure 3.20 shows the analyzed data of public institution facilities. The Euclidean distance technique was applied to calculate the walking distance from the public institution facilities. We created a distance layer of up to 1000m, and classified distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5.

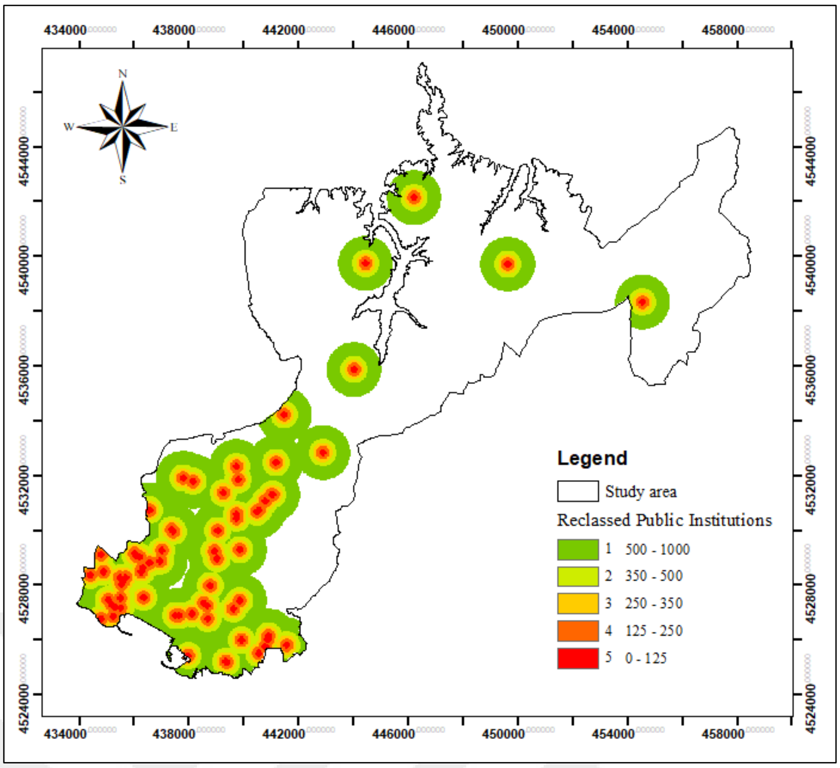

Figure 3.20: Reclassified public institutions distance.

3.6.6. Shopping Malls

A shopping mall is a group of different stores which offer various brands, products like clothing, furniture, technology, restaurants, groceries, entertainment areas, etc. at one place. Nowadays shopping malls are existent in every major city especially where attracts more buyers. People prefer to buy their needs in one place, therefore, visitors looking at a shop that has everything under one roof. Shopping centers generally attract more visitors on weekends. The shopping malls are mostly located near to main roads in the city centers, in case of insufficient parking areas, vehicles are parked on the side of the road and create negative impacts on traffic.

Figure 3.21 shows the analyzed data on shopping malls. The Euclidean distance technique was applied to calculate the walking distance from the shopping malls. We created a distance layer of up to 1000m, and classified distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5.

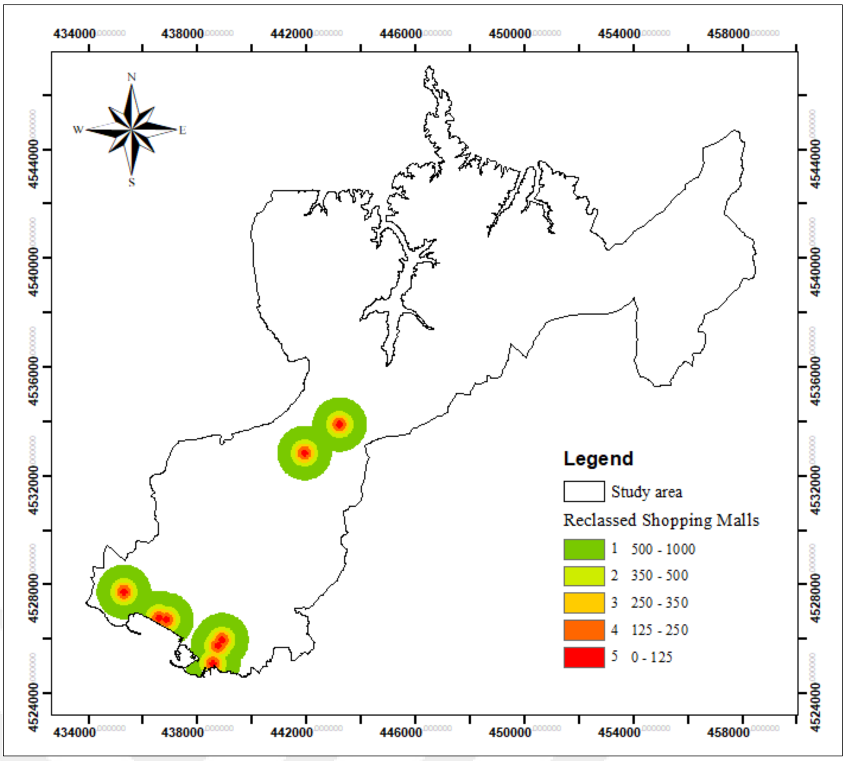

Figure 3.21: Reclassified shopping malls distance.

3.6.7. Sport Facilities

A sports facility is a ground or building in which players do sport. A sports facility can be a sport complex in which a variety of sports like swimming, football, basketball, badminton and many more sports are played and trained. The sports facilities generally open all weekdays but crowded on weekends. Due to a lack of public transportation, the use of private vehicles comes forward. In the case of inadequate parking area, people left their vehicles on the streets.

Figure 3.22 presents the analyzed data on sports facilities. The Euclidean distance technique was applied to calculate the walking distance from the sports facilities. We created a distance layer of up to 1000m, and classified distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5.

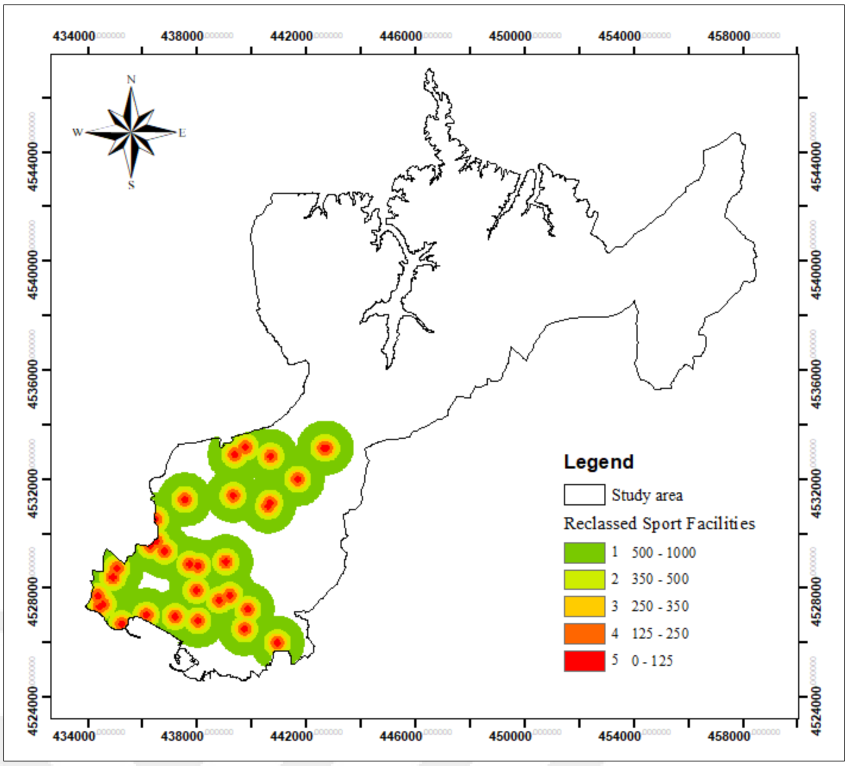

Figure 3.22: Reclassified sport facilities distance.

3.6.8. Green Spaces

Green space is a land covered by trees, grasses or other vegetation partly or completely. Green space includes parks, playgrounds, public seating areas, and kids playing grounds. Green space brings beauty to the city, cleans the air of the environment and has great effect on health. In the case of insufficient parking space, people left their vehicles on streets which have a negative impact on traffic.

Figure 3.23 shows the analyzed data on green spaces. The Euclidean distance technique was applied to calculate the walking distance from the green spaces. We created a distance up to 1000m, and classified distance layer into 5 ranges; 0-125m, 125-250m, 250-350m, 350-500m, and 500-1000m, and giving each range a discrete integer value between 1 and 5.

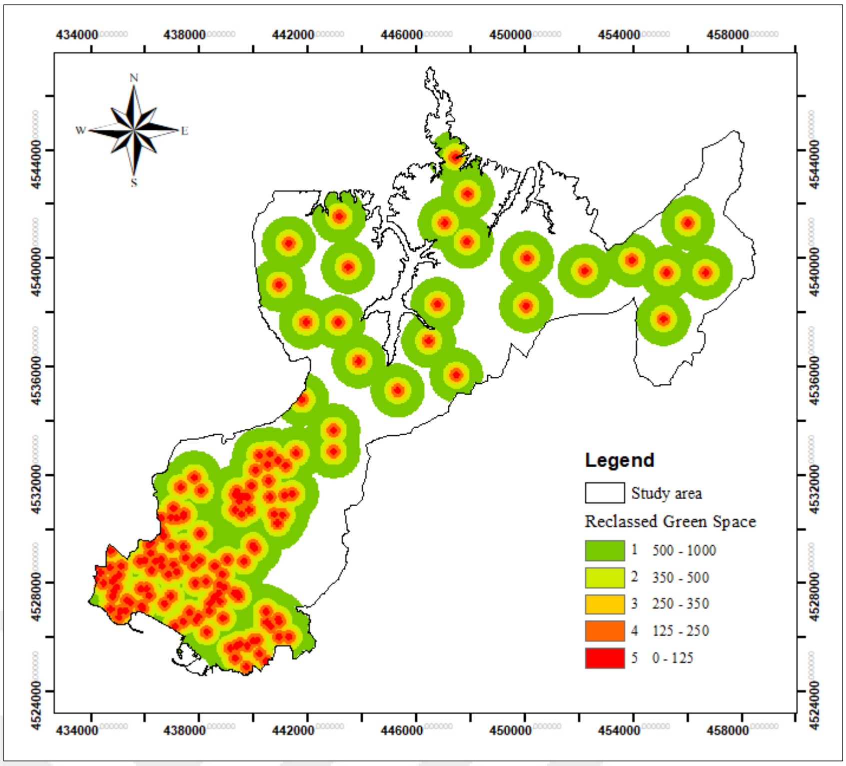

Figure 3.23: Reclassified green spaces distance.

3.7. Determination of Criteria Weights by AHP

For determining parking areas in the study area, transportation criteria, parking criteria, and travel absorption centers were selected as main criteria after consulting with academician experts. The AHP method was used to calculate the weights of criteria and their sub-criteria. In order to calculate the weight of the criteria, we should generate a pairwise comparison matrix. For conducting the pairwise comparison matrix, a questionnaire survey was designed and distributed among experts, managers, and users to obtain their opinions. It is notable that each decision-maker entered the value that considered reasonable for him/her for each member and then individual judgments have been converted into group judgments using their geometrical average. The values used to compare the relative importance of each parameter can be seen in Table 2.3. After generating the pairwise comparison matrix, the weights of criteria and their sub-criteria were computed. Next by using formula (2.1) the CR was estimated to verify whether the judgment is consistent or not. Afterward, the classified maps were integrated into the raster calculator tool and multiplied by their weightage in order to obtain the suitability map of parking areas**.**

As the data were categorized into three main criteria (transportation criteria, parking criteria, and TAC), first the classified layer data of transportation sub-criteria were integrated into the raster calculator tool and multiplied by their weightage, parking sub-criteria, TAC sub-criteria respectively. Subsequently, the three main criteria were integrated into the raster calculator tool and multiplied by their weightage and consequently, the suitability map of parking areas was prepared.

The pairwise comparison matrix of sub-criteria with their corresponding weights are presented in Table (3.1, 3.2, and 3.3) and the overlaid maps of sub-criteria are presented in Figure (3.24, 3.25, and 3.26).

Table 3.1: Pairwise comparison matrix of Transportation criteria.

Criteria	Arteries	Highway	Bus_st	Train_st	Metro_st	Criteria weight
Arteries	1	9	7	5	5	0.568
Highway	1/9	1	1/3	1/5	1/5	0.035
Bus_st	1/7	3	1	1/4	1/4	0.065
Train_st	1/5	5	4	1	1	0.166
Metro_st	1/5	5	4	1	1	0.166
$\boldsymbol{\lambda max = 5.268,\ CI = 0.067,\ RI = 1.12,\ CR = 0.06 < 0.1}$						$\sum \mathbf{1.000}$

The classified layer data of transportation criteria multiplied by their corresponding weights into the raster calculator tool in order to obtain the overlay map of transportation criteria as seen in Figure 3.24.

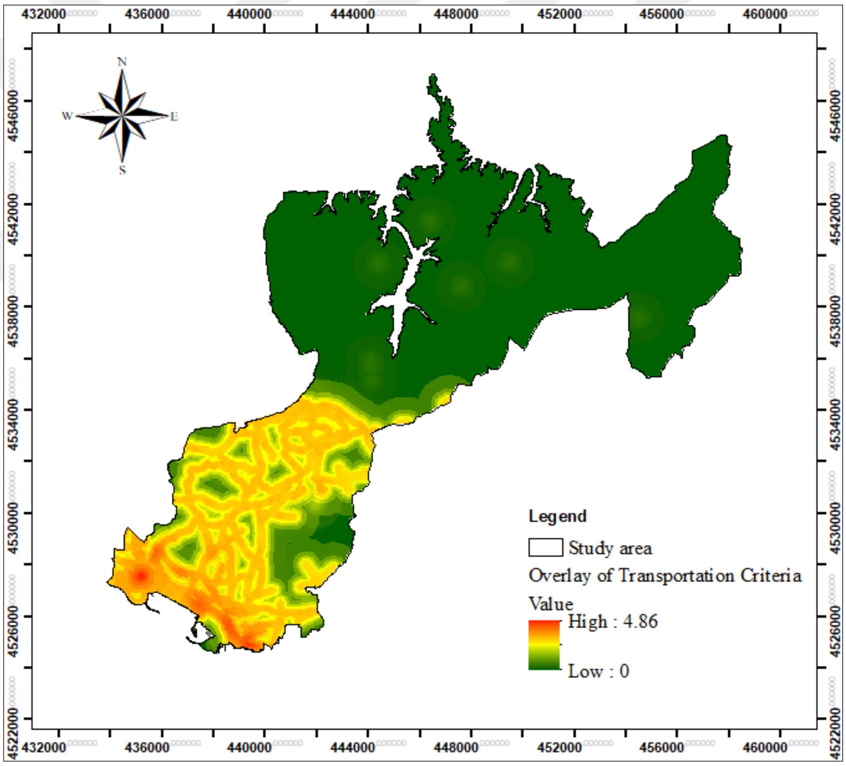

Figure 3.24: Overlaid map of transportation criteria.

Table 3.2: Pairwise comparison matrix of Parking criteria.

Criteria	Existing parking	Slope	Traffic volume	Car ownership	Land cost	Criteria weights
Existing parking	1	7	5	1	3	0.347
Slope	1/7	1	1/3	1/7	1/7	0.035
Traffic volume	1/5	3	1	1/7	1/5	0.062
Car ownership	1	7	7	1	3	0.370
Land cost	1/3	7	5	1/3	1	0.186
$\boldsymbol{\lambda max = 5.273,\ CI = 0.07,\ RI = 1.12,\ CR = 0.061 < 0.1}$						$\boldsymbol{\sum 1.000}$

The classified layer data of parking criteria multiplied by their corresponding weights into the raster calculator tool in order to obtain the overlay map of parking criteria as illustrated in Figure 3.25.

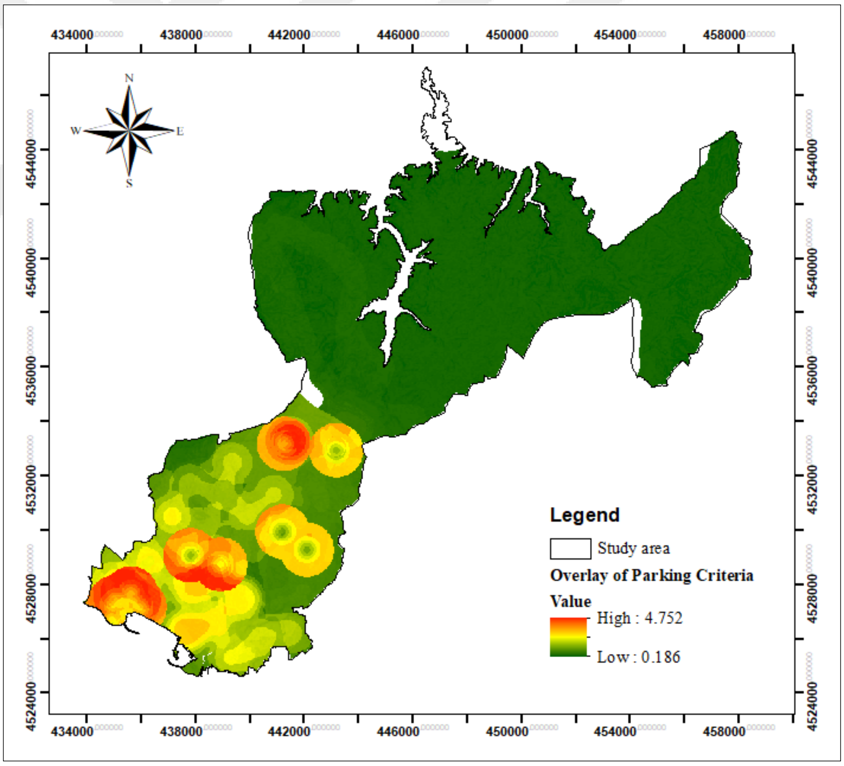

Figure 3.25: Overlaid map of parking criteria.

Table 3.3: Pairwise comparison matrix of TAC.

criteria	Res&work	Cultural	Educational	Health	Public_ins	Sports	Shopping malls	Greenspace	Criteria weights
Res&work	1	9	9	5	7	9	5	9	0.436
Cultural	1/9	1	1/2	1/7	1/3	1	1/9	3	0.028
Educatinal	1/9	2	1	1/7	1/5	3	1/7	5	0.042
Health	1/5	7	7	1	3	7	1	9	0.172
Public_ins	1/7	3	5	1/3	1	5	1/5	5	0.084
Sports	1/9	1	1/3	1/7	1/5	1	1/7	1	0.023
Shopping mall	1/5	9	7	1	5	7	1	9	0.197
Greenspace	1/9	1/3	1/5	1/9	1/5	1	1/9	1	0.018
$\boldsymbol{\lambda max} = \mathbf{8.893}$, $\boldsymbol{CI} = \mathbf{0.128}$, $\boldsymbol{RI} = \mathbf{1.41}$, $\boldsymbol{CR} = \mathbf{0.091} < \mathbf{0.1}$									$\sum \mathbf{1.000}$

The classified layer data of TAC multiplied by their corresponding weights into the raster calculator tool in order to obtain the overlay map of TAC as illustrated in Figure 3.26.

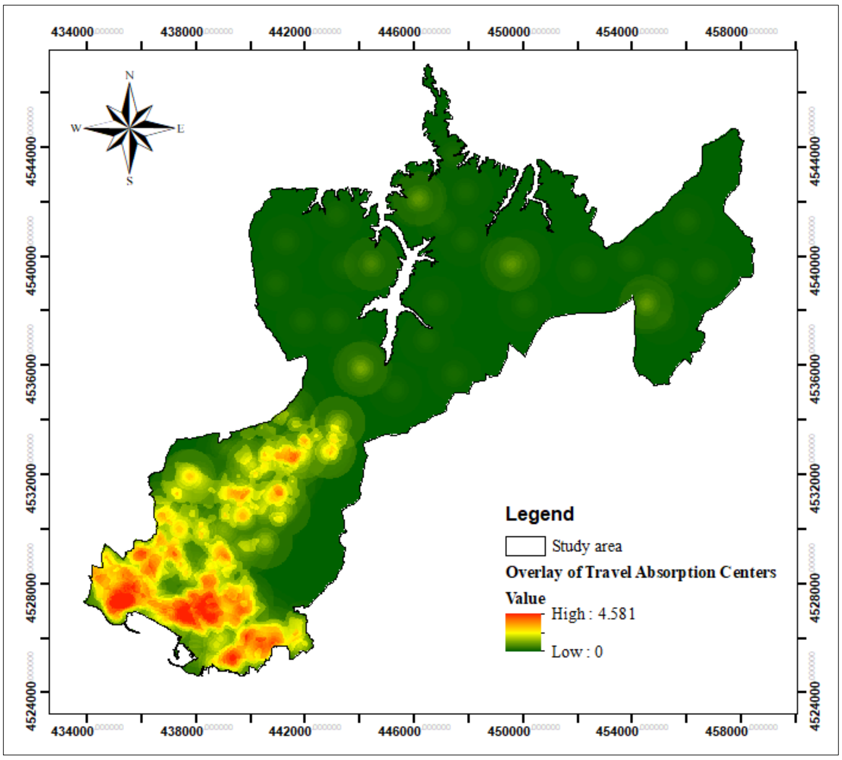

Figure 3.26: Overlaid map of TAC.

In order to reach the final result, it's necessary to combine the main criteria as well. The pairwise comparison matrix of criteria with their weights was presented in Table 3.4 and the final result that was obtained from the overlaying of main criteria or overlaying of the three above figures was illustrated in Figure 3.27.

Table 3.4: Pairwise comparison matrix of main criteria.

Criteria	Transportation	Parking	TAC	Criteria weights
Transportation	1	5	2	0.559
Parking	1/5	1	1/5	0.089
TAC	1/2	5	1	0.352
$\lambda max = 3.054$, $CI = 0.027$, $RI = 0.58$, $CR = 0.052 < 0.1$				$\sum 1.000$

The layer data of criteria integrated into the raster calculator tool and multiplied by their weightage with the aim of generating the suitability map of parking spaces, as displayed in Figure 3.27.

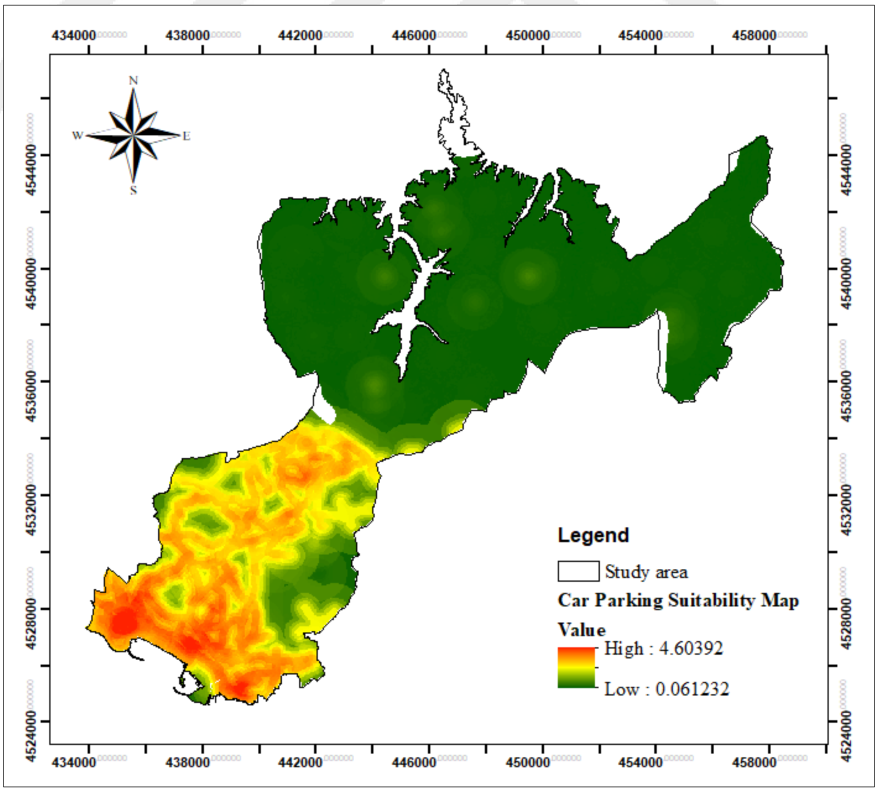

Figure 3.27: Car parking demand suitability map.

As a result of GIS-AHP integration, the parking suitability map shows that the red-colored areas depict high numbers which indicate high demand. The south and southeast of the study area are the most promising and suitable for building parking areas.

4. PARKING DEMAND-SUPPLY ANALYSIS

Geographic data can be defined as the data directly or indirectly related to the location/position. With today's developing technology and communication tools, almost all kinds of data sets can be defined as geographic data. Thus, datasets representing fixed and variable transport infrastructure can be managed with geographical information technologies. When geographic datasets are managed in a coordinated structure in databases, then, the development of decision support tools and policymaking will be enabled.

Geographic information technologies can provide decision support in various disciplines such as urban planning, disaster management, and transportation planning. In planning studies, optimum site selection analysis can be performed according to the determined criteria with decision rules, the data can be analyzed and designed. Similarly, in transportation planning studies, the analysis functions can be used in the selection of transportation infrastructure and facility location. For instance, it can be used to determine the public transport route, the logistic distribution points, and the location of parking lots.

In this method, by using geographic analysis and map algebra functions, we try to balance the parking demand and supply. Due to increasing number of vehicles, irregular construction in urban areas and excessiveness of the population in urban areas on another hand, and at the same time lack of parking areas caused critical problems in transportation planning. For having sufficient transportation management, the parking supplies should meet the parking demand on transportation infrastructure. In this approach, by using GIS techniques, a novel approach was developed to solve problems for determining the optimum locations of parking areas. In the second part, the modeling approach for car park demand analysis was determined. In the third part, network analyst techniques and site selection techniques were performed to specify the best location for parking areas. The location-allocation technique of network analyst was implemented relevant to parking demand.

4.1. Modeling Parking Demand Analysis

Parking demand should be modeled as an abstraction providing the proper representation of the real world in a virtual environment. For modeling parking demand, the activities representing human behavior about parking should be determined and then identified in space and time. Due to the complex nature of these activities and their interaction with land use functions, it is impossible to calculate certain parking demand. The parking demand is changeable in the complementary time period during the day and night. Besides, parking demand varies reasonably depending on land use functions in urban areas.

An abstraction of the real world is necessary to model parking demand in a GIS environment. In the most basic sense, almost all elements influencing parking demand are expressed in a "structure" having a certain volume. Data sets are available and can be obtained for residential areas and workplaces to calculate the geographic distribution of fixed demand weights. However, a dynamic model, rather than certain approaches, should be designed for demand analysis. Considering this issue, the scope of parking problems can be examined in two parts as parking demand and supply.

Digital representation of a structure defining parking demand and supply can be located with point vector geometry that represents polygon structures. All these supply and demand locations have to be defined with x and y coordinate pairs in a common Projected Coordinate System. There is no database provided by local governments that determine the parking demand of building units given the actual parking supply. Therefore, the data sets should be collected and managed for parking demand analysis. The number of houses and workplace(s) in a building, number of vehicles, capacity of parking and their relationship with other factors, and the space they occupy should be modeled in an integrated manner in the geographic database.

In parking demand-supply analysis, the data should be analyzed and calculated with the utmost quality and should have a generalization capability to upscale when necessary. A raster-based calculation determines the parking demand and supply with the smallest pixels. For example, as shown in Figure 4.1, parking demand, functional parking, on-street parking and underground parking facilities of independent units in buildings are represented in point geometry and thus parking demand value can be specified as a result of raster-based calculations and map algebra operations according to the algorithm. Regarding the map algebra calculation (Figure 4.1), the blue pixels indicate places where car parking demand increased, while the red pixels indicate places where car parking supply is high [3].

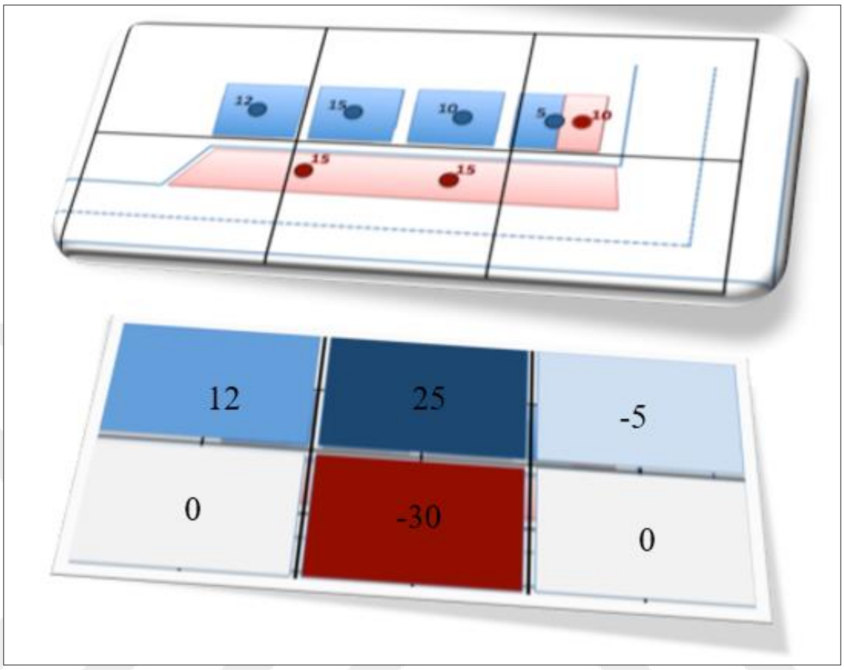

Figure 4.1: Representation of parking Demand-Supply calculation.

Determining parking demand is considered as a problem based on location/position in the GIS. Within the modeling scope, the problem-solving approach should be assigned with geographic analytics steps, which can be explained as follows; [71].

Defining the problem: The problem has been firstly expressed in simple and identifiable sub-steps. For example, parking demand analysis including housing (night) demand, workplace (day) demand, dynamic demand, and parking supply analysis was modeled geographically.

Specifying the data: The available datasets were assigned and integrated into a geographic database including raster or vector geometry with related data.

Selecting the method: Regarding the availability of data, the appropriate geographic analytics techniques were selected in the solution of the problem. The method was designed in a software environment with the application process and steps. For instance, the ArcGIS Toolbox tools were modeled in the Model Builder environment and developed with Python.

Processing the data: Process steps were performed with the selected analytic tools and the results were prepared accordingly.

Examining the result: The results were mapped statistically and reported according to the degree of importance.

4.1.1. Defining the Problem

In determining the parking demand, the scope of the problem can be observed in two general sections as demand and supply;

Demand: it covers parking demand that is essential for existing houses and workplaces and can be determined according to parking behavior on land use.

Supply: it covers all available parking spaces such as off-street parking, marginal parking, private parking and functional parking.

The general approach for modeling the parking problem, fixed demand and dynamic demand should be estimated within the scope of parking demand-supply analysis.

A. Fixed demand

Fixed demand is determined as a priority because it is tangible and predictable. It can be calculated with the accumulation of housing (night) and workplace (day) demands;

Housing (night) demand: It indicates the parking demand for settlements expressed as a fixed demand. Usually, the daily time period of housing demand is between 18:00 (evening) and 06:00 (morning).

Workplace (day) demand: It indicates the parking demand for employees in workplaces expressed as a fixed demand. The daily time period of workplace demand is from 06:00 (morning) to 18:00 (evening).

Figure 4.2a illustrates the time period of housing and workplace parking demand. Consequently, the integration of housing and workplace demand determines the fixed parking demand [3].

B. Dynamic demand

Dynamic demand includes all movements and human activities other than fixed demand such as business activities, public services, entertainment, shopping, education, social activities and others, in which the demand is continuously changing based on time and place. In this study, dynamic demand was divided into three time periods as illustrated in Figure 2b, and as mentioned below [3];

- The time period between 08:00 (morning) and 18:00 (evening) representing dynamic demand for workplaces such as business and public services.
- The time period between 08:00 (morning) and 24:00 (evening) representing dynamic demand for workplaces such as social and recreational purposes.
- The time period for 24 hours representing dynamic demand for workplaces such as health facilities.

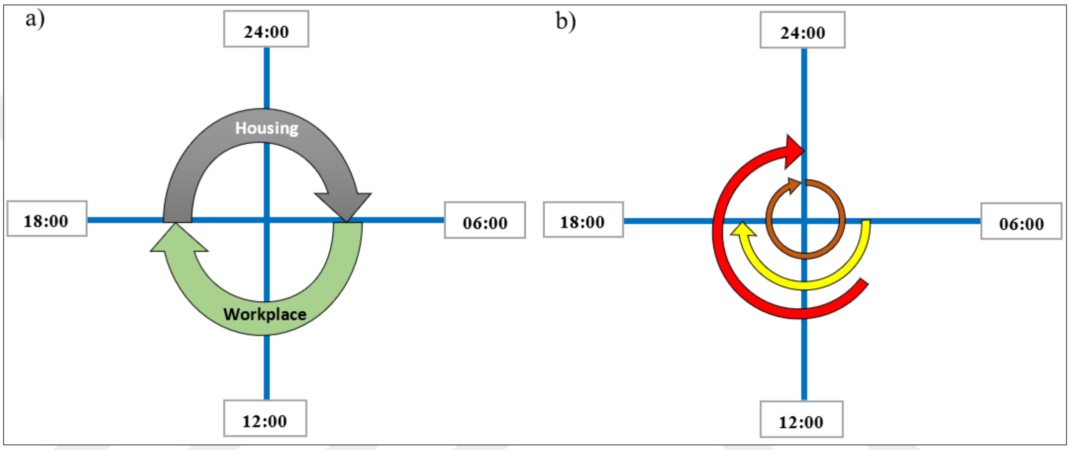

Figure 4.2: (a) Time cycles of fixed demand and (b) dynamic demand.

4.1.2. Data Specification

Parking demand-supply analysis requires extensive and detailed collection of geographic and non-geographic data. The geographic data for this study were acquired from the Istanbul Municipality, while non-geographic data were adopted from the transport assessment survey which had been developed within the context of the Istanbul Transportation Master Plan (IUAP). The data collected for this study area are summarized as follows;

- Building data including location, the number of housing and workplace units, and working cycle.
- Road network datasets.
- Land use datasets.
- Current parking facilities with their capacity.
- Candidate parking facilities.

- The IUAP survey regarding parking behaviors including; the ratio of car use, the ratio of remaining cars in the daytime, the ratio and the number of vehicle visits based on their functional types.
- Demographic data like car ownership, population density, and employment at the neighborhood level.

4.2. Method Selection and Spatial Analysis Process

4.2.1. Housing Demand Analysis

The housing parking demand depends on the number of housing in each building and the ratio of car ownership. Hence, buildings were converted to point geometry and then the number of independent units of housing in each building were algebraically multiplied by the ratio of car ownership to determine the housing parking demand. This parking demand was determined by analyzing 50x50m pixels. The ratio of car ownership, accepted minimum 0.5 for each housing, was obtained from the Istanbul Transportation Master Plan (IUAP) survey at the neighborhood level. Equation (4.1) and Figure 4.3 demonstrates the housing demand;

$$HousingDemand_i = H_i \ x \ A_k \tag{4.1}$$

- H_i = number of housing units of building i;
- A_k = the ratio of car ownership of neighborhood k;

where: $\forall_i A_k \ (i \in k \wedge A_k \geq 0.5)$

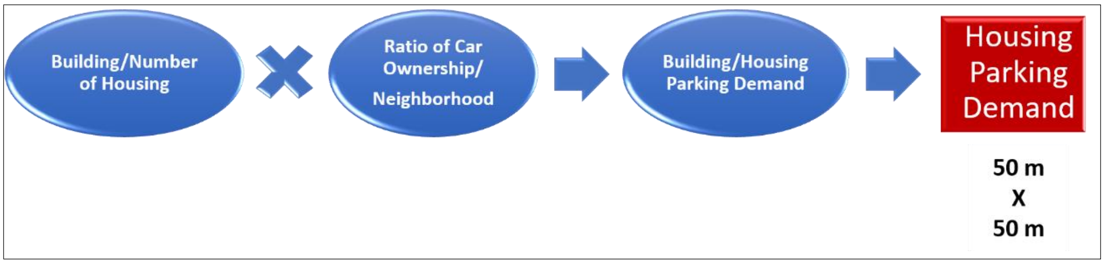

Figure 4.3: Housing parking demand analysis.

After calculating the housing demand, vector geometry was converted to raster data with dimensions of 50x50m. In this process, the demand values of points falling within each pixel were summed and printed on pixels, as illustrated in Figure 4.4.

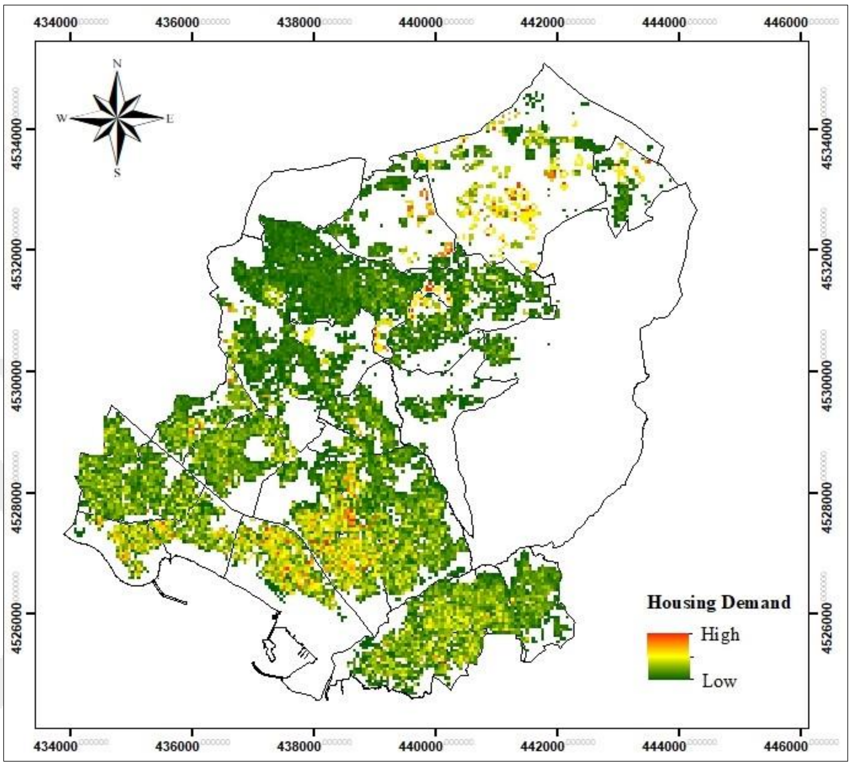

Figure 4.4: Housing parking demand.

For determining parking area demand, the *Model Builder* application of ArcGIS 10.3 software was used. ArcGIS *Model Builder Interface Geoprocessing* is used to automate multiple processes and methods within the GIS.

4.2.2. Workplace Demand Analysis

The workplace parking demand depends on the number of workplaces and the behaviors of car users. Considering the number of employees at the neighborhood level, the number of workplace units in a building and workplace areas was calculated and geographically distributed across the buildings. Thus, the number of employees was determined for each building. The ratio of car use at the neighborhood level was algebraically multiplied by the number of employees to determine the workplace parking demand of each building. Equation (4.2) and Figure 4.5 demonstrate the workplace parking demand;

$$WorkplaceDemand_i = W_{oi} \; x \; B_k \qquad (4.2)$$

$$W_{oi} = \frac{W_{ok}}{\sum_{i=1}^{n} W_{ik}} (W_i \; x \; A_{ri}) \qquad (4.5)$$

- W_{oi} = The number of workers of building i;
- W_{ok} = The number of workers of neighborhood k;
- W_{ik} = The total workplace area of neighborhood k;
- W_i = The number of workplace units of building i;
- A_{ri} = The area of building i;
- B_k = The ratio of car use of employees for neighborhood k;

where: $\forall i \; \forall k \; (i \in k)$

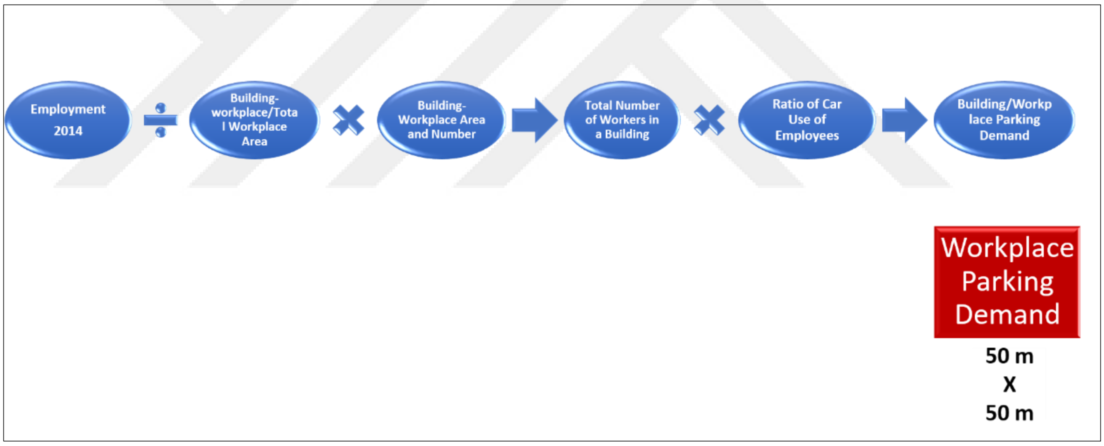

Figure 4.5: Workplace demand analysis.

After calculating the workplace demand, vector geometry was converted to raster data with dimensions of 50x50m. In this process, the demand values of points falling within each pixel were summed and printed on pixels, as illustrated in Figure 4.6.

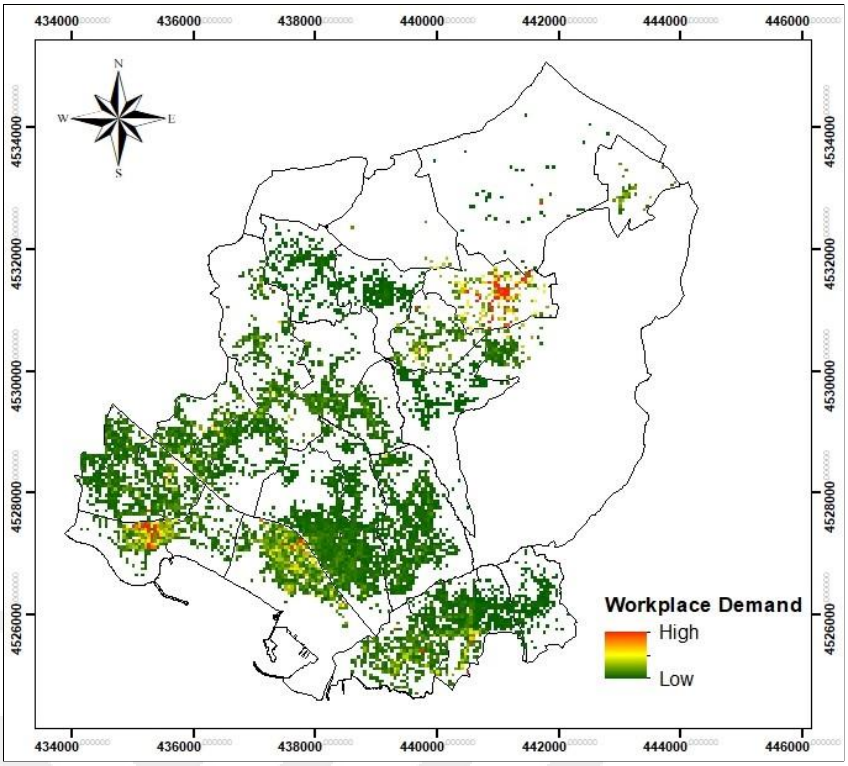

Figure 4.6: Workplace parking demand.

4.2.3. Fixed Demand Analysis

Fixed parking demand was calculated by the integration of housing and workplace parking demands. Land use zones were used to calculate fixed parking demand in terms of housing, workplace, and mixed land-use areas. In the areas where land use is identified as residential or workplace, the time periods were considered and the housing and workplace analysis values in relevant pixels were used to represent fixed parking demand. In mixed areas where land use is considered as residential and workplace, the ratio of remaining cars in the daytime at the neighborhood level was algebraically multiplied by the housing demand and summed with the workplace demand to calculate the fixed parking demand. Equation (4.4) and Figure 4.7 demonstrate the fixed parking demand;

In mixed land-use areas;

$$FixedDemand_i = WorkplaceDemand_i + (HousingDemand_i \ x \ C_k) \qquad (4.4)$$

In any other areas;

$$FixedDemand_i = HousingDemand_i > 0 \wedge WorkplaceDemand_i = 0 \qquad (4.5)$$

$$FixedDemand_i = WorkplaceDemand_i > 0 \land HousingDemand_i = 0 \qquad (4.6)$$

- C_k = The ratio of remaining cars in daytime for neighborhood k;

where: $\forall i \; \forall k \; (i \in k)$

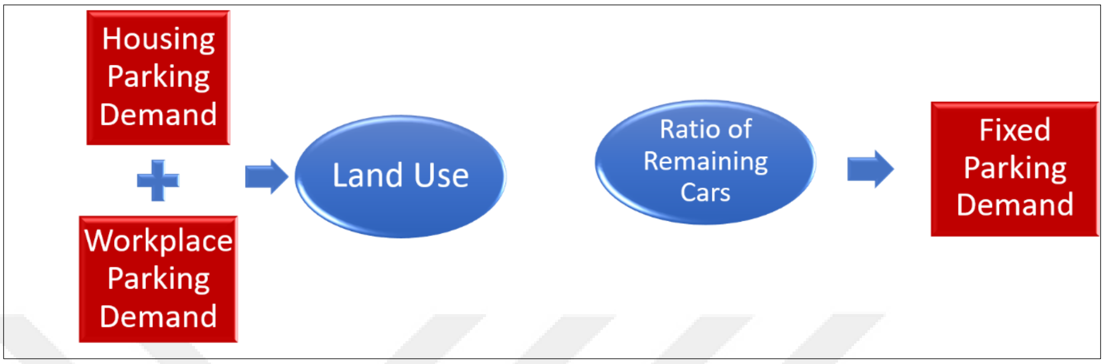

Figure 4.7: Fixed demand analysis.

The results were converted to raster data with dimensions of 50x50m. In this process, the demand values of points falling within each pixel were summed and printed on pixels, as illustrated in Figure 4.8.

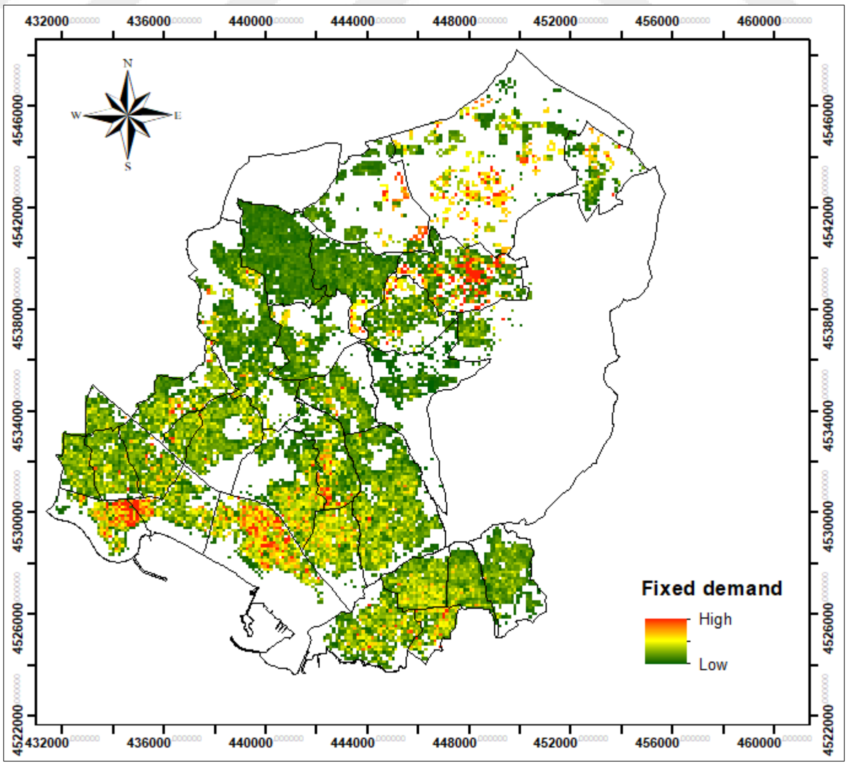

Figure 4.8: Fixed parking demand.

4.2.4. Dynamic Demand Analysis

The building dataset includes functional groups and each building was defined with function types and time periods. Regarding time periods, buildings were defined at 8, 16, and 24 hour periods. An assessment survey provides information about the ratio and the number of vehicle visits at the neighborhood level. These vehicle visits were calculated based on their functional types such as business and public services, education, shopping, social activities, sports, entertainment, and health. By considering this ratio, the attraction ratio of each building regarding their function value was calculated at the neighborhood level. To determine the dynamic demand, the attraction ratio was algebraically multiplied by the number of car visits at the neighborhood level according to their functional types. Equation (4.7) and Figure 4.9 demonstrate the fixed parking demand;

$$DynamicDemand_i = D_{kl} \times D_k \tag{4.7}$$

where: $\forall k \forall l \; \forall i \;\; (i \in k \; \wedge i \in l)$

- D_{kl} = the attraction ratio of function l in neighboorhood k;
- D_k = the number of dynamic car visit in neighboorhood k;

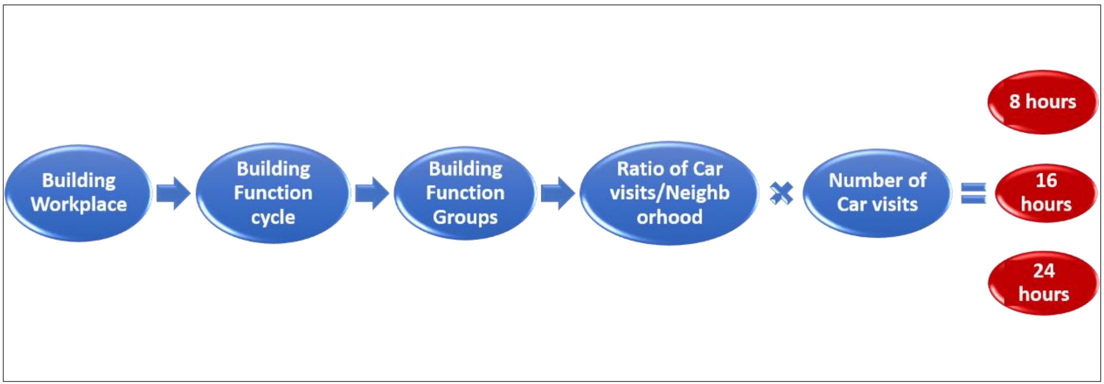

Figure 4.9: Fixed demand analysis.

The dynamic demand was calculated in three different time periods separately. The combination of these dynamic demands gives us total dynamic demand. The results were analyzed in 50x50m pixel dimension, as shown in Figure 4.10.

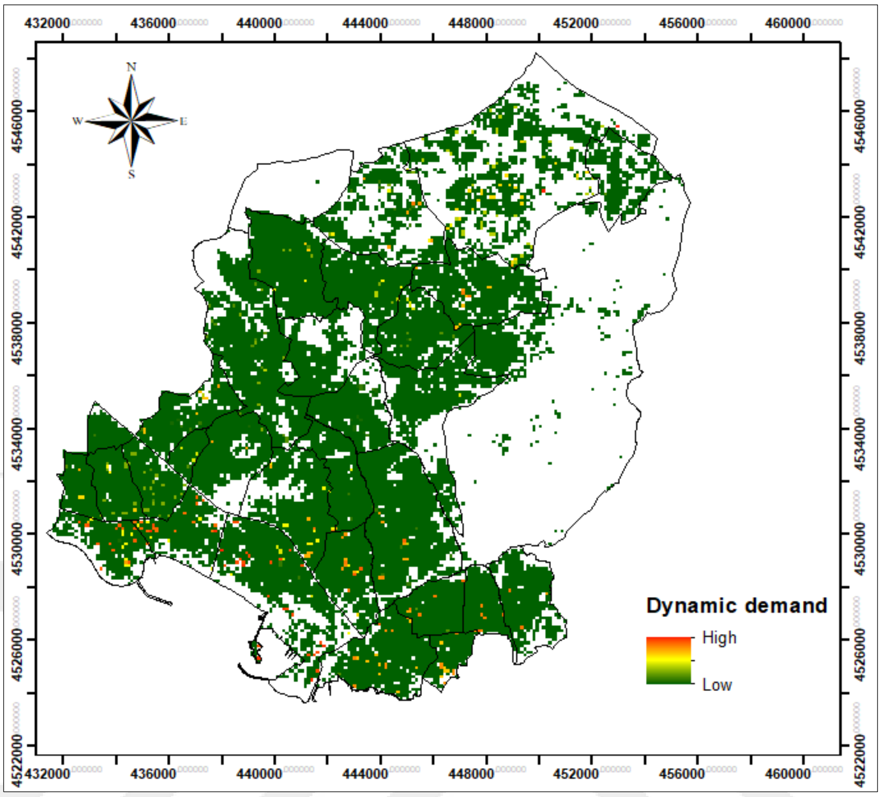

Figure 4.10: Dynamic parking demand.

4.2.5. Parking Supply Analysis

Parking supply includes all available parking areas such as indoor parking, off-street parking, private parking and functional parking. Private parking supply especially meets parking demands in commercial and mixed land use areas. By considering each existing parking area, its capacity was algebraically summed and subsequently the parking supply was determined. The results were converted to raster data with dimensions of 50x50m. In this process, the supply values of points falling within each pixel were summed and printed on pixels, as displayed in Figure 4.11.

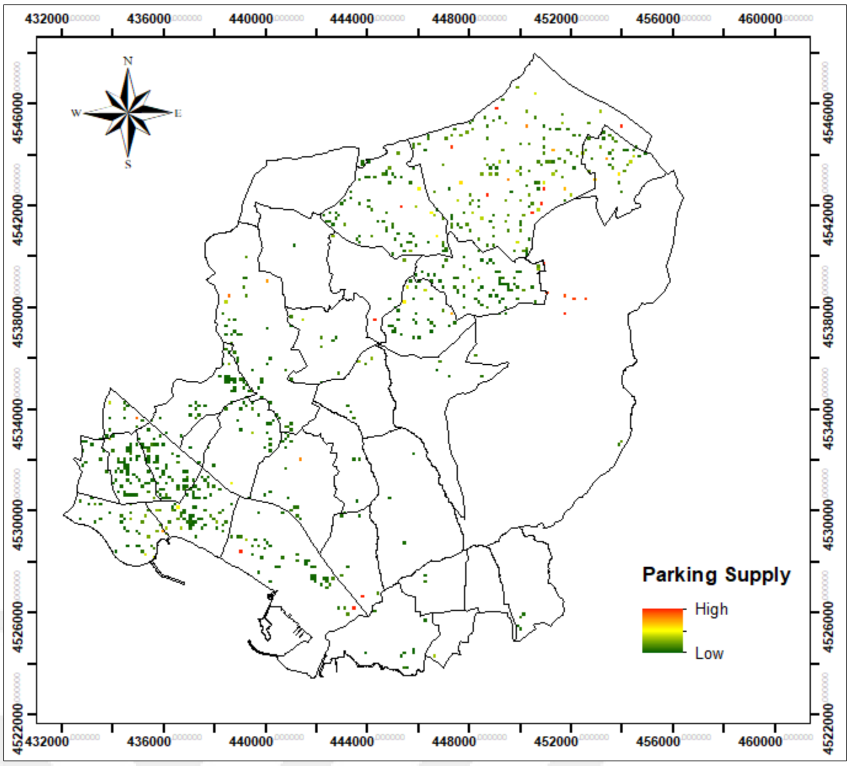

Figure 4.11: Parking supply.

4.2.6. Determining Demand and Supply Balance

The parking lots are mostly located inside the building or on the roadside. Private parking supply especially meets parking demand in commercial and mixed land use areas. By considering each existing parking area, its capacity was algebraically summed, and the parking supply was subsequently determined.

Fixed and dynamic parking demand of a building or structure was eliminated and summed up by using map algebra and calculation techniques Equation (4.6). Fixed parking demand and dynamic parking demand are independent variables. Therefore, these demand values were subtracted from the calculated parking supply as a result of demand analysis. The result was analyzed in a 50x50m pixel size as demonstrated in Figure 4.12.

$$Demand_i = FixedDemand_i + DynamicDemand_i - Supply_j \qquad (4.6)$$

- $Demand_i = The\ total\ demand\ of\ any\ building/structure$

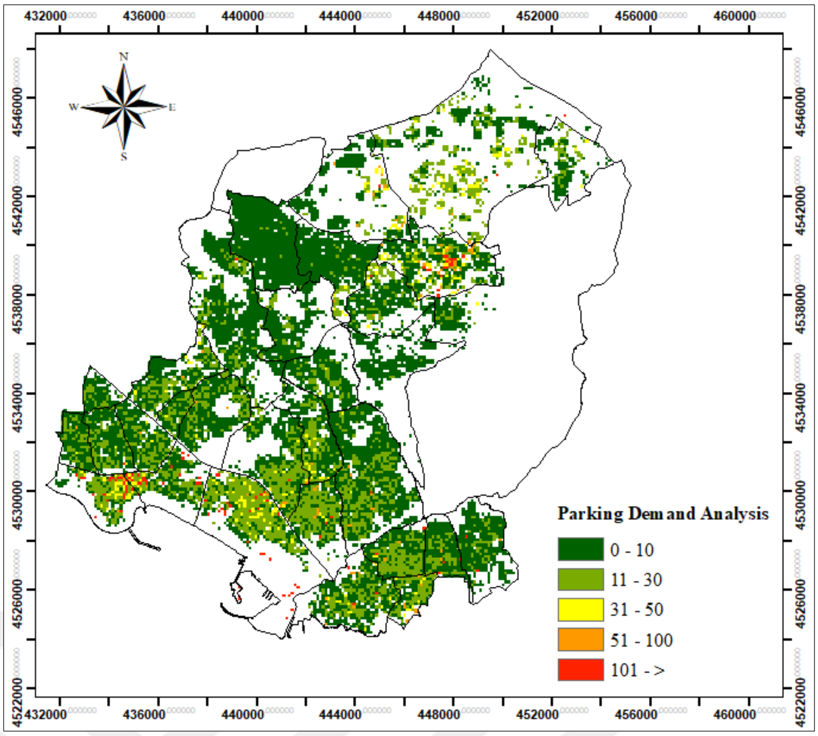

Figure 4.12: Parking Demand Analysis.

4.3. Evaluation of Results

Based on housing (night) demand analysis, a need for 82,047 parking areas was determined in the Pendik district. The neighborhoods with the highest need are Yenişehir, Kavakpinar, and Kaynarca (Table 4.1).

Based on workplace (daytime) demand analysis, a need for 25,901 parking areas was determined in the Pendik district. The neighborhoods with the highest need are Kurtköy, Bati, and Kaynarca (Table 4.2).

Based on fixed (housing + workplace) demand analysis, a need for 97,667 parking areas was determined in the Pendik district. The neighborhoods with the highest need are Kaynarca, Kurtköy, and Yenişehir (Table 4.3).

Dynamic demand was calculated in three-time cycles per day separately. Out of the workplace and residential purposes, the possible parking demand for functions was calculated regarding the time cycles; such as business and public services in the 8-hours cycle, social, sport, and entertainment in the 16-hours cycle, and hospital in the 24-hours cycle. Since these three dynamic demands were combined, the cumulated number of dynamic demands in Pendik district is 26,344 parking spaces. The neighborhoods with the highest need are Kaynarca, Bati, and Doğu (Table 4.4).

The sum of fixed and dynamic demands was calculated as 124,011 and can be expressed as total parking demand. When the total parking demand and parking supply were calculated together, the results will be specified the parking need in Pendik district. As a result, Pendik parking need is 33,249 parking areas.

Table 4.1: Housing demand in neighborhoods.

Name	Housing Demand
YENİŞEHİR	7271
KAVAKPINAR	6986
KAYNARCA	6318
FEVZİ ÇAKMAK	4484
ÇAMÇEŞME	4336
GÜZELYALI	3525
ESENLER	3403
VELİBABA	3206
DUMLUPINAR	2983
ORHANGAZİ	2945
DOĞU	2682
ÇINARDERE	2660
BATI	2627
SÜLÜNTEPE	2566
KURTKÖY	2361
ÇAMLIK	2293
FATİH	2160
YENİ MAHALLE	2067
AHMET YESEVİ	2066
ERTUĞRUL GAZİ	1941
BAHÇELİEVLER	1830
ŞEYHLİ	1694
GÜLLÜ BAĞLAR	1581
ESENYALI	1531
SAPAN BAĞLARI	1515
YAYALAR	1425
HARMANDERE	1100
ORTA	822
YEŞİLBAĞLAR	739
SANAYİ	479
RAMAZANOĞLU	460

Table 4.2: Workplace demand in neighborhoods.

Name	Workplace demand
KURTKÖY	5992
BATI	3649
KAYNARCA	3556
GÜZELYALI	1318
DOĞU	1274
VELİBABA	1173
ŞEYHLİ	895
ESENYALI	803
BAHÇELİEVLER	737
KAVAKPINAR	715
ÇAMÇEŞME	703
ÇINARDERE	665
YENİ MAHALLE	540
FEVZİ ÇAKMAK	502
GÜLLÜ BAĞLAR	452
ORHANGAZİ	398
DUMLUPINAR	368
SANAYİ	360
ORTA	341
HARMANDERE	271
YEŞİLBAĞLAR	250
YAYALAR	214
ESENLER	144
SAPAN BAĞLARI	122
ÇAMLIK	119
ERTUĞRUL GAZİ	79
YENİŞEHİR	70
FATİH	53
SÜLÜNTEPE	49
AHMET YESEVİ	48
RAMAZANOĞLU	42

Table 4.3: Fixed demand in neighborhoods.

Name	Fixed Demand
KAYNARCA	8529
KURTKÖY	8247
YENİŞEHİR	7249
KAVAKPINAR	6916
BATI	5690
FEVZİ ÇAKMAK	4141
VELİBABA	4128
GÜZELYALI	3947
ÇAMÇEŞME	3674
ESENLER	3364
DOĞU	3360
DUMLUPINAR	3095
ÇINARDERE	3024
ORHANGAZİ	2978
ŞEYHLİ	2508
SÜLÜNTEPE	2460
ÇAMLIK	2399
YENİ MAHALLE	2387
BAHÇELİEVLER	2281
ESENYALI	2089
AHMET YESEVİ	1965
GÜLLÜ BAĞLAR	1955
ERTUĞRUL GAZİ	1933
FATİH	1887
YAYALAR	1509
SAPAN BAĞLARI	1492
HARMANDERE	1342
ORTA	1028
YEŞİLBAĞLAR	824
SANAYİ	779
RAMAZANOĞLU	486

Table 4.4: Dynamic demand in neighborhoods.

Name	Dynamic demand
KAYNARCA	9117
BATI	3221
DOĞU	3086
YENİŞEHİR	2441
ÇAMÇEŞME	1049
GÜZELYALI	1037
ESENYALI	705
KAVAKPINAR	669
FEVZİ ÇAKMAK	581
ORHANGAZİ	574
ÇAMLIK	573
KURTKÖY	550
FATİH	524
AHMET YESEVİ	362
ÇINARDERE	331
BAHÇELİEVLER	225
VELİBABA	203
YENİ MAHALLE	198
ERTUĞRUL GAZİ	147
DUMLUPINAR	131
ŞEYHLİ	130
SAPAN BAĞLARI	115
SÜLÜNTEPE	98
ESENLER	90
GÜLLÜ BAĞLAR	63
ORTA	61
RAMAZANOĞLU	27
HARMANDERE	18
YAYALAR	14
YEŞİLBAĞLAR	5
SANAYİ	1

4.4. Location-Allocation Analysis for Site Selection

For determining optimum locations of parking areas, the location-allocation techniques of network analysts were implemented. The demand map that was created with raster-based map algebra was converted to point-based vector map. Demand points with their demand weights can be seen in Figure 4.13.

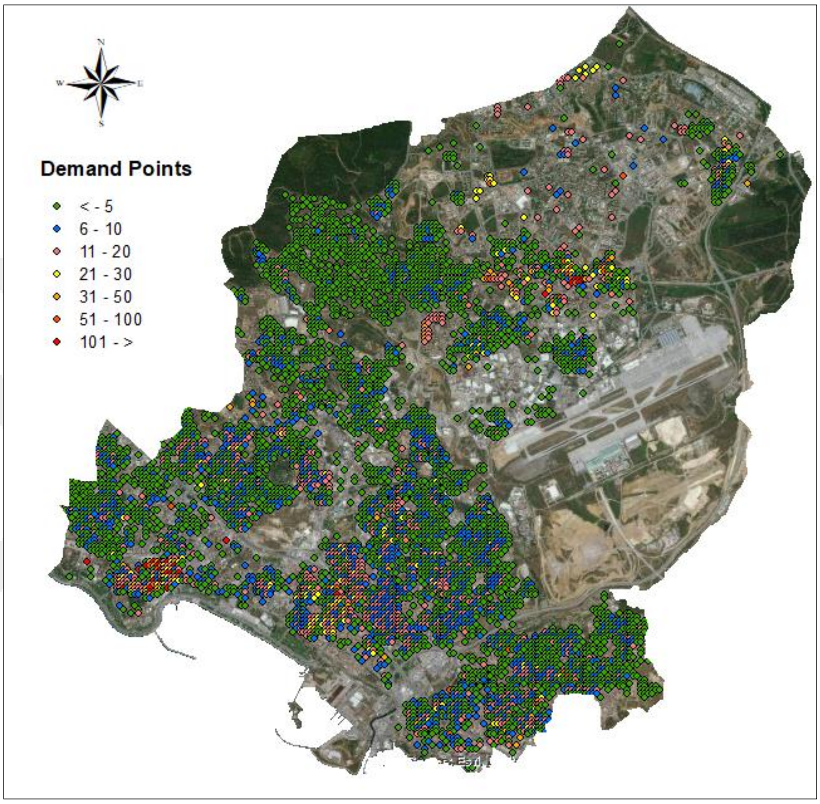

Figure 4.13: Vectorized demand map.

Data sets used in location-allocation problems are summarized below and illustrated in Figure 4.14;

- Facility: “Current” and “Candidate” parking areas which are included in the analysis to service the demands regarding distance and time constraint.
- Demand points: Vectorized demand map that defines the demand points with weights.
- Road network: Road network dataset used to calculate the drive time or distance between facilities and demand points.

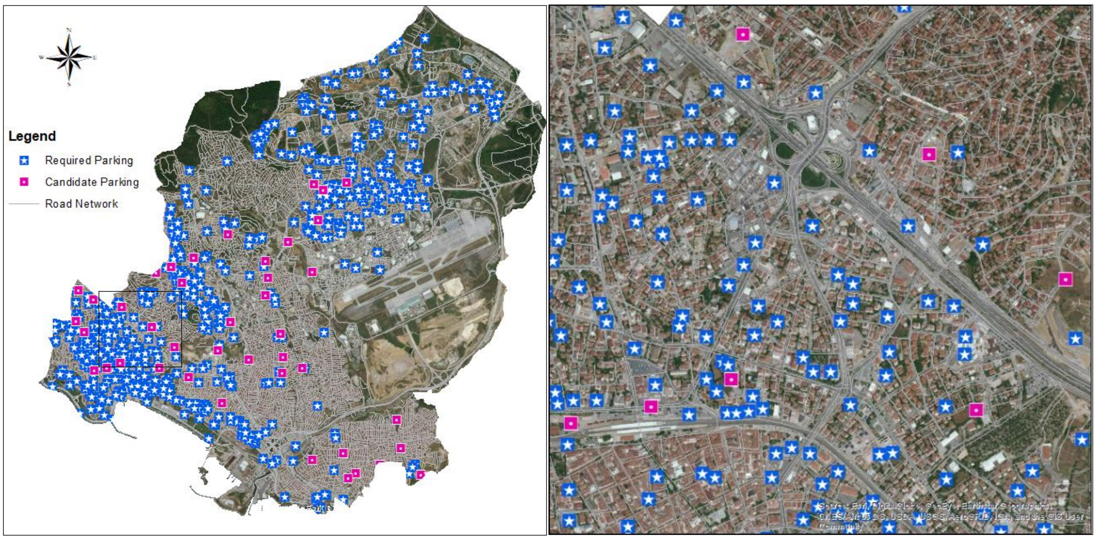

Figure 4.14: Basic components of location-allocation problem.

For determining the optimum location of facilities, the four heuristic models of location-allocation were chosen, because they have been used and considered to be suitable for supporting the planning of facility locations by many decision makers and researchers. These chosen models were; The P-median model or Minimize Impedance (MI), the Minimize Facilities model (MF), the Maximize Coverage model (MC), and the Maximize Attendance model (MA).

Application of location-allocation in each problem type requires time cost or distance constraint to be added in the impedance cut-off between demands and facilities. In this study, a distance of 500 meters was used as an impedance cut-off between demands and facilities over the case study.

The network analyst of ArcGIS software works with vector data not with raster data, so for the basic components of location-allocation techniques, facility and demand must be in vector data. Therefore, the pixel-based parking demand was removed and converted to vector point geometry with their demand weight.

First, Maximize Capacitated Coverage was implemented considering the capacity of required parking facilities to determine the parking demand and supply balance as illustrated in Figure 4.15.

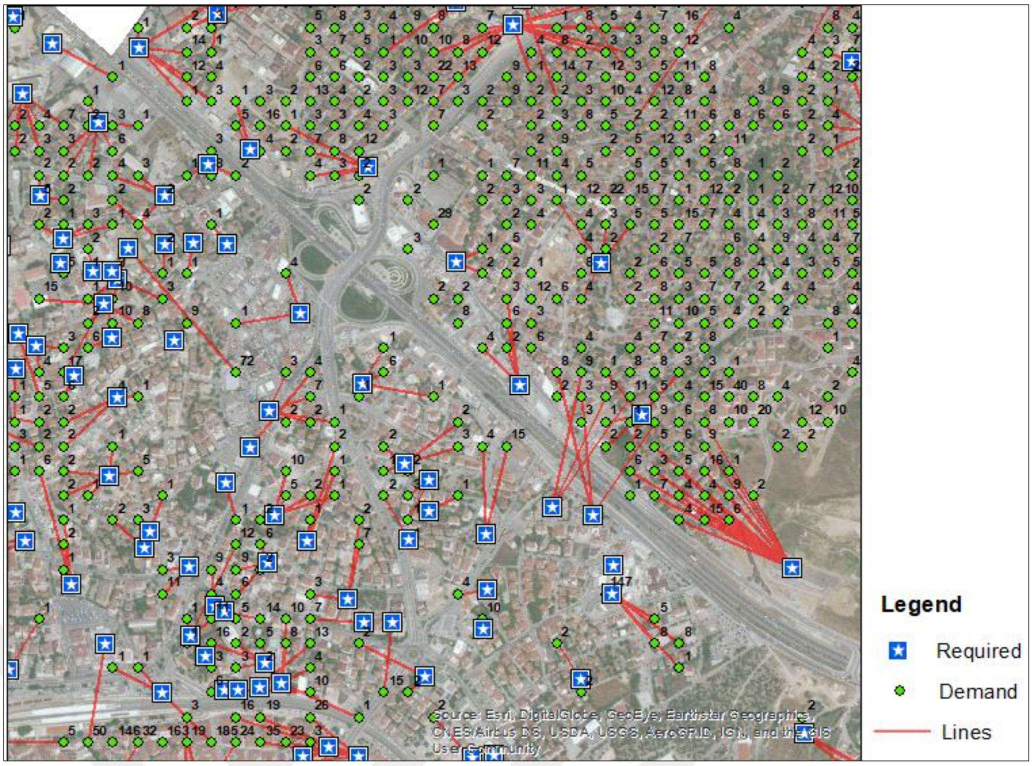

Figure 4.15: Allocating of required parking based of the capacity.

The analysis from applying the maximize capacitated coverage found that 40,211 demands were allocated to facilities and 67 required parking facilities did not allocate any demands. In other words, 67 facilities with a total capacity of 20,607 were not covered any demands.

The reasons that 67 facilities were not covered any demands can be listed as, some facilities are located far away from constraint distance, some are located near to Pendik border that may be service for another districts, some facilities with high capacities were belongs to the airport and remaining facilities are located in places where the demands were covered by other facilities.

The results indicated that some facilities did not cover demands that are located within the distance constraint due to two reasons. First, the capacity of the corresponding facility had been filled and facilities serve the demand without exceeding their capacity. Second, despite having the capacity to cover some more demand, due to restrictive demand weight, it could not cover.

The result indicated that, facilities that covered 40,211 demands have a total capacity of 70,154. Therefore, in some cases, facilities with high capacity covered low demands and places with high demands were covered with low capacity of facility and some demands remained without coverage or without allocating.

The result also showed that, facilities with location name of 247, 613, 785, 624, 383, 619, 133, and 618 with the capacity of 5551, 1733, 1440, 1020, 1000, 903, 898, and 883 respectively were not covered any demands. Location name; 247, 624, 619, 133, and 618 are belongs to the airport, therefore, these facilities did not cover any demand. The remaining facilities were belonging to shopping malls.

Next, we implemented the P-median for "required" parking facilities to locate the demand points within the 500m-distance constraint. Then, P-median was applied once more for "candidate" facilities to locate the remaining demand points. The same process was repeated with the MC, MF, and MA models. The result of p-median and maximize coverage can be seen in Figure 4.16.

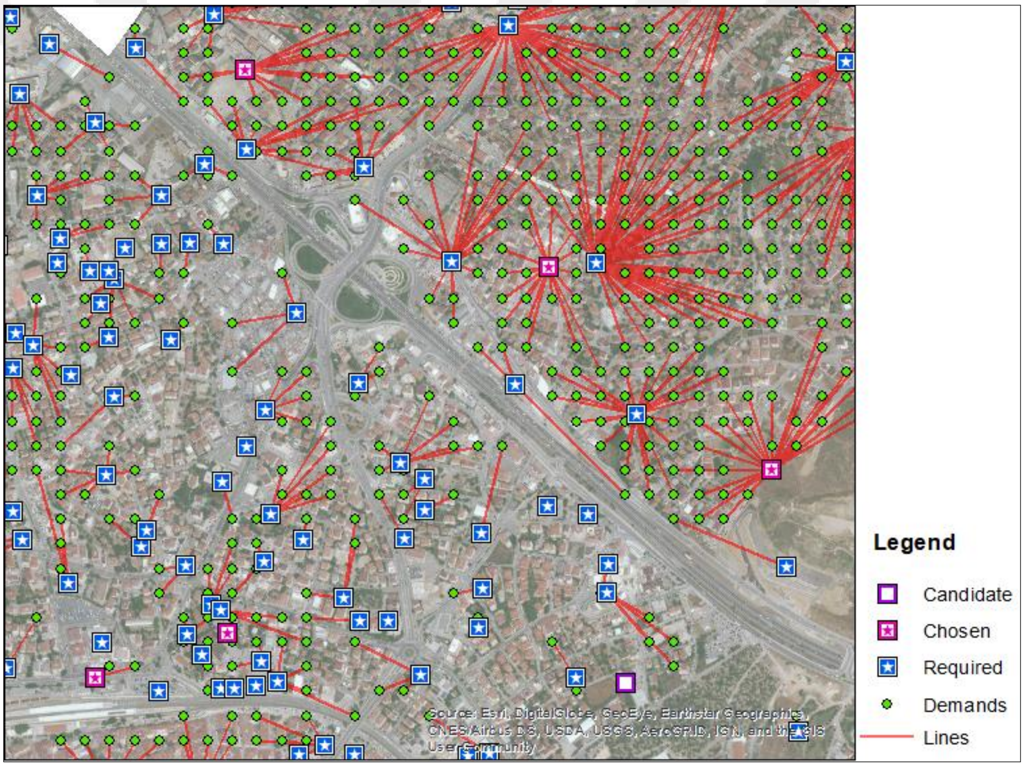

Figure 4.16: Result of applying the p-median and maximize coverage models.

P-median and maximize coverage models find the best locations for building parking areas among candidate facilities that would cover the greatest amount of demand within the specified distance. Figure 4.17a illustrates our findings of the parking facilities and the unsuitable locations for building parking areas. Figure 4.17b illustrates the remaining parking demand.

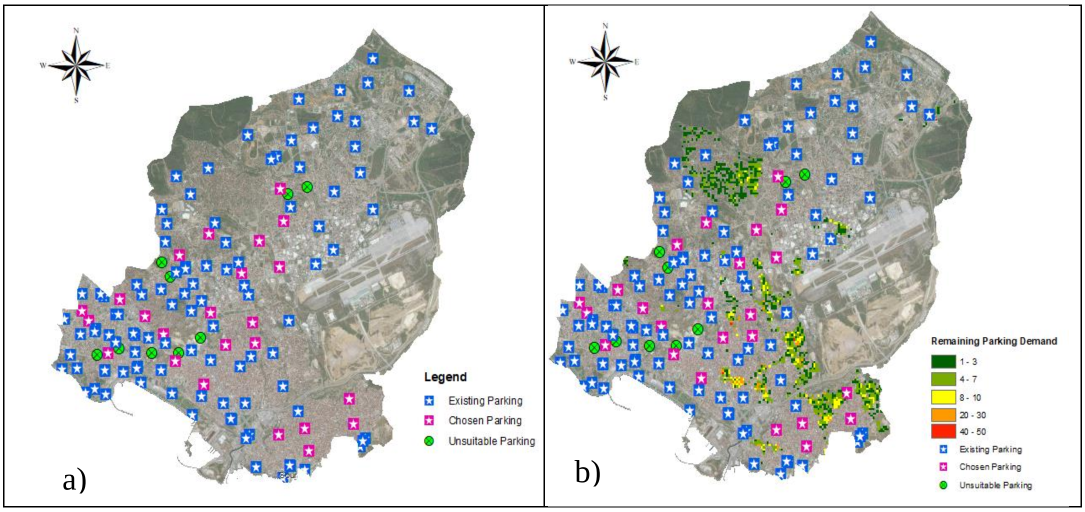

Figure 4.17: (a) Locating parking area and (b) Remaining parking demand.

4.3.1. Results of Applying Location-Allocation Models

Minimize Impedance or P-median is the first model implemented in the analysis with maximum distance constraint of 500m. By implementing this model to the facilities for covering the parking demands, the analysis results found that facilities covered 107.052 parking demands out of 123.941. The results also indicate that among 859 facilities, just 109 facilities did not cover any parking demand. Among 109 facilities, there is only 5 candidate facilities that did not cover any parking demand.

The reason why those facilities did not cover the parking demands are based on the issues explained before; locating far from parking demands, locating in Pendik border, belongs to the airport, and located in places where the parking demands were already covered by other facilities. It’s important to mention that 5 candidate facilities remain without covering any parking demand due to their positions. They were located on places where either there are no parking demands, or the parking demands were already covered by another facilities.

By implementing the second MC and the last MA models to the parking demands, the results demonstrated that the parking demands which were covered by those models are similar to those by the MI model.

By applying the third MF model to the parking demands, the analysis found that facilities covered 107.052 parking demands similar to the MI and MC models. The difference from previous two models is the number of facilities which covered parking demands in a 500m distance constraint. The MF model decreased the number of selected facilities. The results show that 143 facilities out of 859 facilities were not covered any parking demands, among 143 facilities there is only 43 candidate facilities. According to the results of MF, the 43 candidate facilities out of 61 candidates were planned in inappropriate locations.

4.3.2. Comparison of the Four Location-Allocation Models

This section presents the comparison between the results of four location-allocation models that were implemented in this dissertation research. The comparison was based on the total parking demands that each model covers with the number of parking facilities. The goal of this section is to compare amongst these models to discover which models have the best coverage or more coverage than others.

After implementing these models to the same dataset (same parking demands and same number of required/candidate parking facilities), this research found that the results acquired from implementing the MI and the MC models by considering the same distance constraint are similar. The results generated from those models have exactly the same results; selecting the same number of facilities with same maximum coverage of parking demands and same facilities that did not cover any parking demand.

Additionally, the results generated from implementing the MA model type are quite similar. The only difference is that the MA allocates a ratio of the demand weight for each parking demand, whereas, the MI and the MC models allocate the demand weight for each parking demand. The results demonstrated that the three above mentioned models with the same number of parking facilities reached to their maximum coverage for parking demands. Despite the fact that these models are with two altered tactics, they still reached to the same results.

In contrast, the third MF model created different results than other models. The only difference amongst the other models is that the number of facilities is not user-defined, in other words, there is no such option to identify the number of facilities for covering the parking demands. The results indicated that the MF have the similar coverage as the MI and MC with the difference of selecting fewer number of facilities.

This research found that the MI, MC, and MA models generate better results than the results generated from applying the MF model. These three models within the same distance constraint provided the same results of covering the parking demands. The results from analysis also found that other model types were performed better than the MF model type because of the covered more parking demands with more number of facilities. Its noteworthy to mention that the number of facilities is important in this research because of the capacity. If a facility covered more parking demands within the impedance cutoff and have less capacity, it would not service effectively. Therefore, in this dissertation study the MI, MC, and MA models were performed better than the performance of MF model.

5. DISCUSSION AND CONCLUSION

GIS is widely used to store, analyze, visualize, integrate, and manage a large amount of data that can support the decision-makers to manipulate and arrange the geographically referenced data. GIS also recognized for having different functions that users able to integrate layers of different scales, from different sources, and different contents. This distinct function of GIS can assist researchers, planners, and policymakers who deal with the finding of optimum locations for both the public and private sectors. On the other hand, GIS includes many functions that can support the decision-makers and investigators who deal with the challenge of finding the best locations for service facilities. For instance, finding the optimal locations for parking spaces.

Traditional methods of determining parking areas are limited by the narrow spectrum of parameter evaluation during parking space allocation. In other words, selecting parking spaces using the traditional ways cannot give us reliable results since it considers very few parameters like the price of land. Therefore, in some cases, this makes parking areas to be located away from the travel absorption centers and far from busy streets, which have negative effects on traffic loads. GIS as a science of spatial analysis, is a worthy scientific approach to determine optimum locations for parking areas. The ability of GIS in selecting suitable sites for parking lots is well captured in the scientific literature. The use of GIS in the field of spatial analysis increases the accuracy of Geomatic works and reliability of the results. In comparison with traditional methods, the use of GIS represents holistic approaches capable of integrating multiple essential parameters simultaneously for effective land resource allocation. Whereas, the allocations of parking spaces in the traditional way have been done by visiting the location without considering all essential parameters.

This dissertation research has considered two different methods for determining parking demands in Pendik district by using GIS. The first method was the integration of the MCDM technique with the GIS and the second approach was determining parking demand-supply analysis within a GIS environment. The first method of this study has focused on preparing the suitability map of parking demand in Pendik district by the integration of GIS and AHP. This approach considered three main criteria as an effective criterion for determining parking demands. These main criteria are transportation criteria, parking criteria, and travel absorption centers. The second method has focused on pixel-based parking demand-supply analysis in Pendik district. This approach concentrated on determining fixed and dynamic demands. In addition, we implemented the four location-allocation models as well for site selections. These models are MI, MC, MF, and MA.

The application of GIS and decision-making techniques together were tested with determining parking demands in the first method. The factors for determining the best location of car parking areas were identified base on literature reviews and opinions of experts. The relationship between criteria and sub-criteria is also specified by literature reviews and experts' opinions. A geographic database of effective factors or criteria has been created and made within a GIS environment. Spatial analysis methods of GIS were researched, and the appropriate process was carried out considering the data structures and characteristics. AHP method was used to evaluate the weight of criteria and sub-criteria. Finally, the pixel-based location selection model was prepared.

In transportation problems, data can be gathered by using geographic information technologies and their effectiveness can be revealed. The relationship between data can be defined and their effects can be discussed. In this way, a complex problem will be solved. Car parking areas, which is a transportation problem, are also a complex problem. For example, if an area is selected as the best location for parking space through defined criteria, this area cannot be a public parcel, or this parcel can be under the ownership of someone. In this case, a high amount of expropriation costs will be needed. Therefore, in order to solve this problem efficiently, more essential criteria should be considered in the workflow of optimal site selection initially. In this study, we attempted to consider more essential criteria.

The results were greatly affected by data quality. Though the parking demand analysis in this research was progressed with qualified data but the quality of data was not the same for all data, the research was developed based on available datasets. The car parking problem is amongst the biggest problem in urban municipalities and metropolitan municipalities of large and developed cities, because it’s not finished but it’s increasing by passing the time. In order to solve this problem, the institutions should be developed in data-producing technologies, sharing protocol should be signed between the institutions, produce the data in real-time, and the reproduction of data should be prevented. The parking demand-supply analysis that needs more accurate and statistics data should be updated in the database in real-time. If the data quality is improved, more accurate results can be presented.

After increasing the number of vehicles and growing population, the Pendik districts suffer from the lack of parking areas. Therefore, the four location-allocation models were applied to the results of parking demand-supply analysis to evaluate the site selection efficiently. It was found that there are some parking demands in the Pendik district uncovered by the current parking lots with a 500m distance constraint. The results indicated that 40211 demands were covered by the facilities that have the capacities of 70154 within the impedance cutoff of 500m. It appears that this dissertation identifies parking lots that are not covered the demands, at the same time, indicates areas with higher demands.

In this dissertation for site selection, we did not create a new model. This study conducted four existing models of location-allocation models. This dissertation found that the location of some facilities is not optimal due to not covering any demands. Even though some of the candidate parking facilities also did not cover any demands.

This dissertation exposed the reasons, why some required, and candidate facilities were not contributed to cover the demands. The reasons are; locating far from parking demands, locating in Pendik border, belongs to the Sabiha Gökçen airport, and located in places where the parking demands were already covered by other facilities.

One of the contributions of this dissertation is to assist the parking policymakers and planners in selecting the proper locations of candidates. The suitability map of parking demands that prepared by the first method can assist and give a prospect to policymakers for selecting the best locations of candidates. Figure 5.1 illustrated the suitability map of parking demand with the candidates parking facilities;

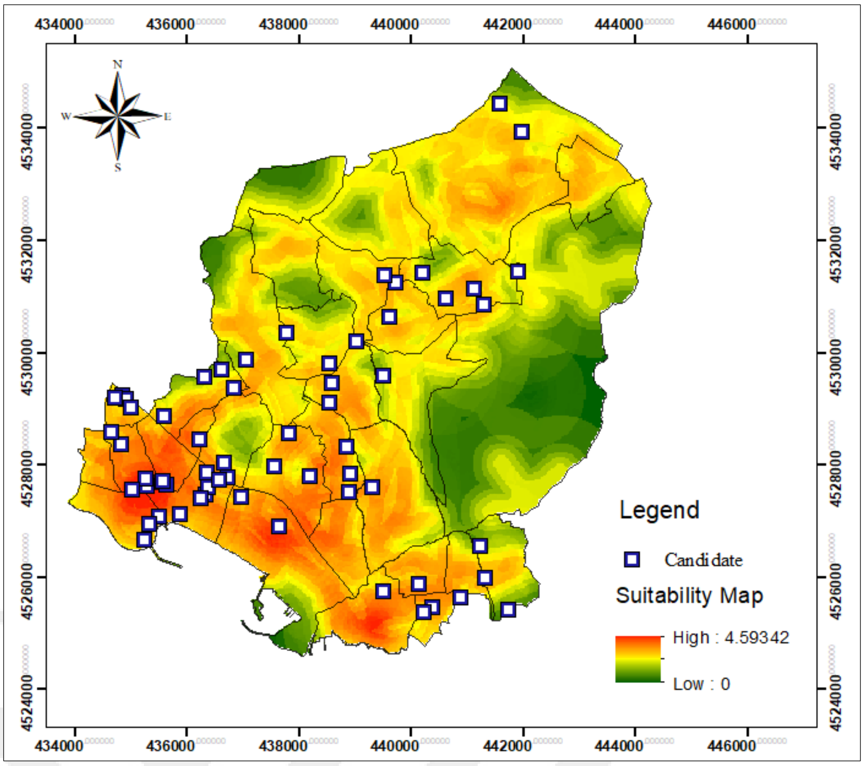

Figure 5.1: Candidate facilities on the parking suitability map.

The above Figure indicated that some candidate facilities located in places where the demand is low and will not cover the demands within the defined impedance cutoff and showed that some candidates located too near to each other. This is one of the biggest reasons that some candidates did not cover any demands.

One of the contributions in this dissertation is applying the location-allocation models for evaluating the site selection and knowing of the way location-allocation models work. It was found that the Minimize Impedance model, Maximize Coverage model and Maximize Attendance model produced similar results when considering the same impedance cutoff.

Although the location-allocation models of Geographic Information System are a significant tool for determining the optimum locations for facilities of private and public sectors. These models also have a problem; they do not consider the capacity. The capacity location problems are not solved by these models. The demands only considered covered or not covered. The demands will be assigned to only one facility not into two different facilities, and the demand will be allocated to its closest facility. Hence, facilities that are placed near to demand points will cover more demands than other facilities. In some cases, these facilities due to covering more demands than other facilities will be overloaded and might affect negatively to the aim of services. For instance, in this study many parking lots located near to the density of demands. So, these parking lots have to deal with many demands than other parking lots. This condition will make these parking lots overloaded.

Another contribution of this dissertation associated with the difference or comparison between two methods implemented in this study for determining the parking demands. The comparison or differences can be explained in Table 5.1;

Table 5.1: Comparison between two implemented methods.

First Method (Integration of GIS and AHP)	**Second Method (Parking Demand-Supply Analysis)**
It can be found extensively in literature reviews.	It cannot be found extensively in literature reviews.
It's not a complex method.	It's a complex method.
Determine the demand values in ranges for the study area.	Determine exact demand values for the region of interest.
It is not so hard to find or prepare data for this method because it does not need more details data.	It's hard to find or prepare data for this method because it does need more details data.
The datasets may or may not be updated but needs qualified data for better and accurate results.	The datasets should be updated in realtime and develop with qualified datasets.
The results by using qualified data can be accurate but not more accurate because the weights of criteria came from judgments of humans.	The results by using qualified data can be more accurate, because no need for any judgments.
Applied different spatial analyst tools in GIS environment.	Applied different spatial analyst tools and network analyst tools in GIS environment.
It provides parking solutions only in the short term.	It provides parking solutions in the short term and also provides parking solutions in medium and long terms for parking strategic managements or parking policymakers.
Determine only the parking demand spaces.	Determine the parking demands in different land uses and times; – Residential: night parking – Non-residential: daytime parking – Mixed: day and night parking
This approach can be applied in developed cities and non-developed cities by considering more effective criteria.	This approach can be suggested to developed cities and implemented in transportation main plan or parking master plan projects.

The allocation of car parking spaces that have been done using the traditional method was not able to consider all the effective parameters and gave insufficient results. This study developed approaches that consider all the effective parameters simultaneously. Concomitant use of GIS and AHP represents holistic approaches capable of integrating multiple essential parameters simultaneously for effective land resource allocation. The integration of the GIS with AHP technique appears to be a highly useful method in dealing with rich spatial data as well as manipulating criteria importance towards defining the optimum locations of parking spaces. The parking Demand-Supply analysis appears to be a highly useful method for selecting parking in urban planning especially in transportation planning and management for policymakers. The first method should be implemented in transportation main plan and the second method should be implemented in the transportation master plan and application zones for determining parking spaces. These novel methods can be applied in developing cities to support the urbanization and transportation. Consequently, we anticipate that these novel integrative approaches, and its future variations thereof, will be instrumental in works determining efficient parking spaces in highly populated urban areas.

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BIOGRAPHY

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APPENDICES

Appendix A: Related conference attendance

Iqbal A.S., Aydınoğlu A.Ç., (2019), “Use of MCDM Technique and GIS for Determining Optimum Location of Car Parking”, Lisansüstü Araştırmalar Sempozyum ve Tanıtım Günleri, Gebze Technical University, 17-18 June, Kocaeli, Turkey.

Iqbal A.S., Aydınoğlu A.Ç., (2019), “Determining Parking Demand by the Integration of Geographic Information System (GIS) and Analytical Hierarchy Process (AHP)”, International Symposium on Applied Geoinformatics, Yildiz Technical University, 7-9 November, Istanbul, Turkey.