REPUBLIC OF TURKEY
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF INDUSTRIAL ENGINEERING

GIS-BASED MULTI-CRITERIA DECISION MAKING FOR EV CHARGING STATION SITE SELECTION

ÜMMÜHAN NİDA EROL
MASTER OF SCIENCE

ADANA 2022

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I hereby declare that all information in this thesis has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all information that is not original to this work.

[Signature]

Ümmühan Nida EROL

ABSTRACT

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Electric vehicles (EVs) are an area that needs to be studied today, as they not only contribute to the economies of countries in the context of dependence on oil but also support more livable and sustainable urban areas. The location selection of electric vehicle charging stations (EVCSs) is one of the most important issues that will improve and increase the use of electric vehicles. In this respect, the purpose of this study is to find suitable locations of the electric vehicle charging stations by combining Geographic Information System (GIS) techniques and Multiple-Criteria Decision Making (MCDM) methods.

Maltepe, Kartal, Umraniye, and Atasehir districts, which belong to the city of Istanbul, are determined as a working area and study is carried out for these districts. In this study, the criteria to be used in the study have been decided first, the Analytical Hierarchy Process (AHP) is used to calculate the weights of these selected criteria. The weighted criteria and the data layers of the districts were analyzed with the help of site selection analysis tools provided by GIS. In the result analysis, the areas where battery stations can be installed in the current working area were determined according to the degree of suitability. The results offer suggestions for forward-looking planning and strategies. With the help of the fields identified by the suitability analysis, 14 alternative station locations have been decided. These station locations provide us with an idea for new battery stations to be installed in the future.

Keywords: electric vehicle, site selection, battery station

ÖZET

ELEKTRİKLİ ARAÇ ŞARJ İSTASYONU YER SEÇİMİ İÇİN CBS TABANLI ÇOK KRİTERLİ KARAR VERME

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Ağustos 2022, 57 sayfa

Elektrikli araçlar yalnızca petrole bağımlılık bağlamında ülkelerin ekonomilerine katkıda bulunmakla kalmayıp, aynı zamanda daha yaşanabilir ve sürdürülebilir kentsel alanlara da destek sağladıkları için günümüzde üzerinde çalışılması gereken bir alandır. Elektrikli araç şarj istasyonlarının konum seçimi elektrikli araçların kullanımını geliştirecek ve artıracak en önemli konulardan birisidir. Bu açıdan, bu çalışmanın amacı Coğrafi Bilgi Sistemi (CBS) tekniklerini ve Çoklu Kriter Karar Verme (ÇKKV) yöntemlerini bir arada kullanarak elektrikli araç şarj istasyonlarının uygun konumlarını bulmaktır.

Çalışmada İstanbul iline ait olan Maltepe, Kartal, Ümraniye ve Ataşehir ilçeleri çalışma alanı olarak belirlenir ve bu ilçeler için çalışma yürütülmektedir. Bu çalışmada öncelikle çalışmada kullanılacak kriterlere karar verilmiştir, seçilmiş olan bu kriterlerin ağırlıklarının hesaplaması için Analitik Hiyerarşi Süreci (AHP) kullanılır. Ağırlıklandırılmış kriterler ve ilçelere ait veri katmanları CBS'nin sağladığı yer seçimi analiz araçları yardımıyla analiz edilmiştir. Sonuç analizinde mevcut çalışma bölgesinde batarya istasyonlarının kurulabileceği alanlar uygunluk derecesine göre belirlenmiştir. Sonuçlar, ileriye dönük planlama ve stratejiler için öneri sunmaktadır. Uygunluk analizi ile belirlenen alanların yardımıyla 14 adet alternatif istasyon lokasyonuna karar verilmiştir. Bu istasyon yerleri gelecekte kurulacak yeni batarya istasyonları için bizlere fikir sunmaktadır.

Anahtar Kelimeler: elektrikli araç, yer seçimi, batarya istasyonu

Dedicated to my mother Ayşe EROL

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Firstly, I would like to express my thanks to my patient and supportive supervisor, Assoc. Prof. Dr. Mustafa GÖÇKEN, whose guidance, support and encouragement have been invaluable throughout this thesis study.

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NOMENCLATURE

EV	: Electric Vehicle
EVCS	: Electric Vehicle Charging Station
HEV	: Hybrid Electric Vehicle
PHEV	: Plug-in Hybrid Electric Vehicle
BEV	: Battery Electric Vehicle
PEV	: Plug-In Electric Vehicles
MCDM	: Multi Criteria Decision Making
MADM	: Multi-attribute Decision Making
MODM	: Multi-objective Decision Making
AHP	: Analytical Hierarchy Process
TOPSIS	: Technique for Order of Preference by Similarity to Ideal Solution
GIS	: Geographic Information System
TurkStat	: Turkish Statistical Institute
DC	: Direct current
IMM	: Istanbul Metropolitan Municipality
ICE	: Internal Combustion Engine

1. INTRODUCTION

Cities are centers of various activities that require efficient and convenient transportation of people and goods. It has been proven by many instances how the transport infrastructure adds speed and efficiency to the progress of a country. Good physical connectivity in rural and urban areas is crucial for economic growth. It can be said that transportation is the lifeblood of cities. Transportation services consist of water transportation, land transportation, and air transportation (Vuchic, 2002).

Fuel-powered vehicles are a common land transport option, which negatively affects the environment and human health. Because they generate some harmful gases such as nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) etc. Harmful gases absorb solar energy and keep the heat on the surface of the earth instead of escaping into space. This heat retention in the atmosphere is called the greenhouse gas effect. Unwanted emissions of greenhouse gases from the burning of fossil fuels have reached a threatening level. Therefore, urgent prevention action is needed by implementing an eco-friendly climate policy. Electric vehicles that do not release greenhouse gases can be a promising solution to combat climate change and environmental pollution issues (Aritra Ghosh, 2020).

Electric vehicles are alternatives to improve environmental conditions because their carbon emission is lower than conventional vehicles. Many countries around the world are aware of the importance of electric vehicles to achieve the goal of reducing greenhouse gas emissions and are organizing new policies for that purpose. For example, the Chinese government has introduced several policy initiatives for promoting EVs. These initiatives are grouped into two categories, monetary and non-monetary. As an example of these policies, financial support has been provided for electric vehicle R&D activities (Li, Yang, & Sandu, 2018).

The first electric vehicles were developed in the 1830s and used non-rechargeable batteries. By the end of the 19th century, commercial electric vehicles had become available. Today, the most common types of EVs are battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and Hybrid electric vehicles (HEVs).

The concept of the BEV is essentially simple, such vehicles only work with one electric battery without a part of the gas engine. HEVs have two or more power sources and are powered by an internal combustion engine with one or more electric motors that use energy stored in the batteries. HEVs allow automobile users to combine electrical and fossil fuel energy. PHEVs provide car users with different driving modes as well as different fuel options, they have an internal combustion engine and an electric motor. They can work with petrol, different conventional fuel and a charged battery (Larminie & Lowry, 2012).

According to international projections, it is known that the life of known oil reserves in the world is decreasing day by day. Depending on the reduced reserves and increased demand, oil prices are estimated to reach very high prices in the coming years. In the near future, the extinction of fossil fuels has accelerated the orientation of people who depend on fossil fuels to electric vehicles in recent years. The sudden increase in renewable resources and slump in fossil fuel consumption is attributed to climate change, energy transition, sustainable energy systems, and clean energy initiatives. The rapid growth of renewable resources brings new design and operational challenges to transition to 100% renewable energy targets. Energy storage systems can help transition from hydrocarbon fuels to renewable resources.

In recent years, the use of electric vehicles has been increasing in Turkey. According to data from Turkey Electric and Hybrid Vehicles Association, in Turkey, sales of BEVs in 2021 have increased approximately three times compared to the previous year. Likewise, a significant increase has been observed for HEVs and PHEVs. In 2021, Renault Zoe is the most sold vehicle brand in Turkey among BEVs. Among the HEVs, the most sold vehicle brand is Toyota Corolla Hybrid. This increase in the number of vehicles increases the demand for charging stations for vehicles. Studies are gaining importance to meet the demand for EVCSs. Charging stations are the fastest growing industry in our country's electromobility area. The charging stations sector, which has been operating in our country for more than 10 years, has become a real industry as of December 2021. Charging stations have achieved their standards, and then new legislation with a specific legal framework has been entered into force. According to the statement made by the Republic of Turkey Ministry of Industry and Technology, it has been decided to support investments by legal entities to build a charging station for electric vehicles (TEHAD).

The electric vehicle charging station is a device that uses electrical energy to charge electric vehicles. Thanks to the constantly evolving technology today, the variety and production of electric vehicles continue to increase. With these vehicles increasing, the demand for stations is increasing day by day. New plans and strategies are being implemented to meet this growing demand, but the demand can only be met with the presence of stations in sufficient numbers and suitable locations. The location selection of EV charging stations is one of the most important issues to enhance the use of EVs. There are many studies that aim to provide appropriate locations for EVCSs, such as optimization and multiple criteria techniques. The main purpose of these studies is to be able to satisfy the demand that will be made due to the increased use of electric vehicles in the long term. In particular, studies that have been integrated into MCDM and GIS in recent years have gained a lot of popularity. This type of study is popularized by the fact that data can be obtained from maps and other existing data can be transferred to the map. In this study, the GIS-based MCDM method is decided to be used. The reason why the geographical MCDM method is preferred in the study is that the study contains both maps and other types of data.

Electric vehicles in Turkey are a source of hope for a cleaner environment, as they reduce environmental damage and reduce our energy dependence on the outside than on internal combustion engines. In particular, the city of Istanbul, where millions of vehicles are used daily, is one of the cities that urgently need to switch to the use of electric vehicles. Istanbul is a city that is constantly evolving and rapidly growing city with its urban structure and socio-economic features. Population placement preferences constantly adapt to changing conditions. One part of Istanbul lies in Europe and the other part lies in Asia, so throughout its history, it has acted as both a barrier and a bridge between two continents. The city of Istanbul, where this cross-continental bridge is located in Turkey, is the lifeblood in all respects for Turkey. The city of Istanbul has been determined to be a working area for reasons such as the high population, the speed of technological developments, the increased use of electric vehicles, and the economic significance of the city.

The thesis consists of six chapters. The introduction section, the first part of the study, is intended to explain the general structure of the study and the information about electric vehicles. In the second section, the Literature review, studies including GIS-based multi-criteria decision making, electric vehicles, location selection, etc. in the literature were examined. In the third section, detailed descriptions of the methods and materials used in the study have been made. In the fourth part, results, analysis, maps, etc. obtained as a result of the study are discussed and evaluated. By the time the fifth section is reached, the methods used in the study and the findings obtained in the study are briefly explained. In the last section, recommendations have been made for new studies in the future. This section provides advice for future studies, such as alternative criteria, location, and workspace.

1.1. Aim and Motivation of the Study

Various studies aiming to find suitable locations for electric vehicle charging stations are increasing nowadays. Because it is necessary to carry out studies on this issue in order to keep up with the increasing demand and technological developments. In this study, it was decided to conduct a study on battery stations of electric vehicles. The main purpose of this study is to find the most appropriate locations of the EV charging stations using the GIS techniques and AHP methods. The study was conducted in the city of Istanbul, Turkey. It covers the Kartal, Maltepe, Atasehir and Umraniye districts of Istanbul. This study is a recommendation for station location selection in meeting the increasing station demands in Turkey.

1.2. Overview of Electric Vehicles

Electric vehicles, unlike conventional gasoline and diesel cars, are environmentally friendly vehicles powered by an electric motor. EVs are the driving force for a better environment today and tomorrow. Many car manufacturers around the world are now starting to reserve a significant portion of their resources for the production of electric vehicles. In addition, various technology companies that operate globally are working on innovative ways to produce EV and EV batteries. In particular, the production policies announced by car companies show that traditional fossil fuel-based cars will disappear over the years (Chan, Chau, & Chau, 2001).

The most commonly used electric vehicles are generally considered in three categories:

- Battery electric vehicles
- Hybrid electric vehicles
- Plug-in hybrid electric vehicles

HEV is a vehicle type that combines two different power sources to provide driving power. This type of vehicle consists of a conventional internal combustion engine (ICE) and a battery/electric motor system. The HEV battery can be charged both while driving and also while the car is stationary. Examples of HEVs are Honda NSX, Ford Mondeo Hybrid, Lexus RX450h, Toyota Yaris Hybrid, Toyota Corolla Hybrid, etc. (Poullikkas, 2015).

There are two types of plug-in electric vehicles (PEVs): battery electric vehicles and plug-in hybrid electric vehicles. BEVs and PHEVs contain a charging socket and a rechargeable battery. PHEVs mainly work with a combination of two power sources, such as batteries and gasoline. The charging of the electric motor can be provided externally because the internal combustion engine and electric motor can work independently on PHEVs. The most powerful feature of the PHEVs is that the electric motor has started to work when the fuel is low. The possibility of the driver being stranded on the road is also reduced. PHEVs are often more expensive than similar conventional and hybrid vehicles, but in some ways, such as fuel savings, some costs can be recovered. Vehicle brands such as Volvo s90 plug-in hybrid, Jeep compass plug-in hybrid, BMW i8 plug-in hybrid, and Cupra Leon plug-in hybrid can be given as examples of PHEVs.

BEVs are wholly electric vehicles with no gasoline engine and rechargeable batteries. BEVs are the only zero-emissions vehicles, as they do not generate any air pollution hazards or harmful emissions caused by conventional gasoline-powered vehicles. Three main concerns prevent potential consumers from adopting BEVs. These concerns are a limited driving range, long charging time, and relatively high price. A variety of solutions are being developed such as increased charging stations, fast charging, and various types of batteries (Zhou, Wen, Wang, & Cai, 2020). Examples of BEVs are Tesla Model Y, Renault Zoe, Hyundai Kona Electric, Tesla Model 3, and Nissan Leaf.

1.3. Electric vehicle history

The history of electric vehicles that have become particularly popular in recent years has been very old. The history of electric vehicles extends from electric vehicles produced in the early 1800s to today's development. The first experimental light-weight electric vehicles appeared in the United States, the Netherlands, and the United Kingdom in the mid-1830. In these early years, there were extensive developments in electrochemistry. In 1859, Belgian Gaston Plante introduced the first lead-acid battery cell. Other chemical cell batteries were developed in these years (Westbrook & Westbrook, 2001).

Between 1880 and 1900, electric vehicles had a golden age. In 1908, however, Henry Ford introduced the new gasoline-powered vehicle, Model T. With Ford's move, the American car market changed from top to bottom. In 1912, electric vehicles were replaced by gasoline-powered vehicles which were more proper for mass production. By the 1960s, a series of air pollution problems were faced, especially due to the intensive production of the factories, the increase in the number of automobiles and the harmful fuels used for heating. After these events, studies on electric vehicles gained importance and speed again in the 1970s, as they caused less damage to the environment (Høyer, 2008).

The fact that electric vehicles have been in our lives for a long time, but in recent years, there have been unbelievable increases in electric vehicle production and sales. Factors that adversely affect human life, such as low fossil fuels and global warming, have become the biggest supporter of electric vehicles in search of new technology. As a result of the request created by this supply, large car manufacturers have made future plans to develop and promote electric vehicles. There are many companies today that produce electric vehicles such as Tesla, BMW, Renault, Hyundai, and Volkswagen. Projects and studies related to electric vehicles are also being carried out in our country.

1.4. Electric Vehicle Charging Stations and Working Principle

However, limited battery capacity and the limited number of charging stations cause range problems, which prevent the mass use of vehicles. The availability of charging stations is required for the adoption of the EV. Charging stations are as important as electric vehicles as they ensure the functionality of the entire system. Therefore, allocating these charging stations in the urban environment is critical to the growth of electric vehicles (Karolemeas, Tsigdinos, Tzouras, Nikitas, & Bakogiannis, 2021).

The increase in electric vehicles will result in a significant increase in demand for electrical energy. In this case, it creates a variety of problems, such as overloading the transformer. Therefore, when installing a charging station, planning with analysis and predictions should be carried out in order to operate the process with minimal problems, taking into account regional capacity and loading conditions (BİRLEŞTİRİCİ et al., 2015).

The charging station system is a structure consisting of components such as electrical energy infrastructure and a charging unit. Charging units perform the energy flow to the electric vehicles within the charging station system. The charge time of an EV depends on the charge level of the battery, the technology in the vehicle, the charging cable used, and the charging station.

There are four different charging modes to charge electric vehicles. These charging modes are shown in Figure 1. Mode 1 is the simplest mode because there is no dedicated circuit or equipment for electric vehicle charging. The use of this mode is limited due to safety risks and limitations and is even prohibited in some countries. Mode 2 is controlled by a control box on the charging cable. This charging mode may take a longer charging time because in general the current flow is set to lower currents for the main outlet. In charging Mode 3, communication is established when EV is connected to the charging station. First, the vehicle reports the current level it can accept to the charging station, and then the station adjusts the current to transfer it to the vehicle. Mode 4 is the only charging mode that provides direct current (DC) fast charging. Charging Mode 4 requires a current converter, so the charging station usually has more volume than a simple station (Hardman et al., 2018).

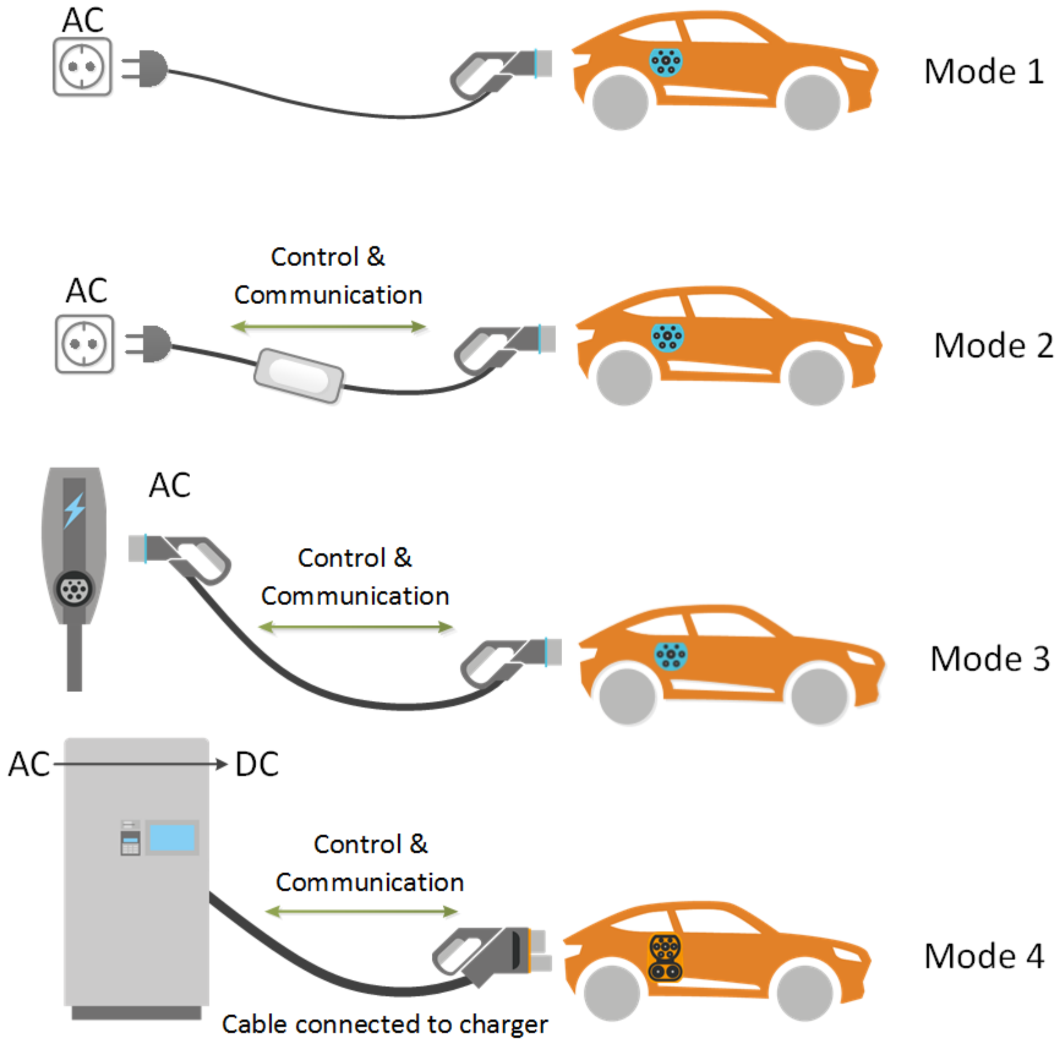

Figure 1.1. Charging Modes for Electric Vehicles.

1.5. Future of Electric Vehicle

Due to the increased production and acceptance of electric vehicles worldwide, the demand for vehicle battery stations continues to increase. Over the last decade, electric vehicles have been attracting considerable attention by buyers, sellers, and researchers as ecological means of transportation. One of the biggest concerns about the use of electric vehicles is that we have to wait for hours while the vehicle is being recharged and the vehicle consumes its energy quickly. Solutions such as fast charging for these types of problems are developed by vehicle companies. Because of the growing number of vehicles, fast charging stations will be used more often and problems with the power grid infrastructure are expected to occur in the future due to higher charging power (Bryden, Hilton, Dimitrov, de León, & Cruden, 2019).

One of the most expensive parts of electric vehicles is the vehicle battery. Due to this expensive cost, the work continues today to produce batteries more cheaply. The aim is to produce the battery cheaply and to provide the most effective driving use from this battery. Only the cost cannot determine the consumer's choice, it is available in other important features. When buying a new vehicle, consumers take into account a variety of features such as performance, aesthetics, and reliability. Vehicle production work in line with the customer's request and demand continues to be carried out by vehicle companies (Pandey, Manocha, & Saini, 2020).

2. LITERATURE REVIEW

Some studies in the literature related to electric vehicles have been examined. In recent years, studies in the literature have shown that GIS-Based MCDM methods are often used to analyze and evaluate electric vehicle charging stations. Among the studies obtained as a result of literature research, the predominantly used GIS-Based MCDM techniques were included in the study.

Arijit Ghosh et al. (2021) conducted a new study based on GIS in 2021, to decide on the appropriate location for electric car charging stations in Howrah, India. Four main factors and thirteen sub-factors are taken into account for the selection of the charging area.

Linzhao (2020) is another scientist who contributes literature by using GIS. In Linzhao's study, GIS was used to implement the GIS-based AHP method to obtain the optimal location of electric car charging stations in Shenzhen City. The primary purpose of this study is to develop solutions for the scientific planning of charging stations, taking into account technological environmental, and social factors. Analysis was carried out based on the criteria and as a result, 18 alternative station positions were selected.

Using GIS and multiple criteria decision-making methods, Kaya, Tortum, Alemdar, and Çodur (2020) contributed to the literature. Various problems are encountered with the use of electric vehicles, such as range and charging status. This study provides a recommendation for optimal planning of the EVCS.

Guler and Yomralioglu (2020) conducted their research for 3 districts in Istanbul, using the integration of MCDM and GIS techniques to find the appropriate locations for electric car charging stations in their work. Fuzzy Analytical Hierarchy Process (FAHP) and AHP methods were used to acquire the weights of the criteria. Some criteria used in the study: Transportation stations, Income rates, Park areas, Petrol stations, Shopping malls, Population density, etc. As a result of this study, the grading of the charging stations from the most suitable area to the unsuitable area was made.

In their study, Erbaş, Kabak, Özceylan, and Çetinkaya (2018) applied a GIS-based MCDA approach to handle EVCS site selection. FAHP and technique for order preference by similarity to ideal solution (TOPSIS) methods were applied to choose the optimal EVCS sites. 15 different variables were used in the study. The study was conducted in the city of Ankara, the capital of Turkey. As a result of the study, the locations of 12 existing stations were evaluated and suitable locations for new stations were determined.

In the year 2020, Singh, Singh, and Vaibhav (2020) reviewed the factors affecting the adoption of electric vehicles. A total of 211 research articles were published between 2009 and 2019. has been selected and studied. It has been determined that studies on the influencing factors for the adoption of electric vehicles have increased significantly in recent years. High purchase prices and limited driving range have been found to be significant barriers to EV adoption. Consumer features such as age, gender, and education are the most important factors in determining purchase intentions. In general, it is concluded that socio-demographic and psychological factors have a positive effect in predicting consumers' EV adoption.

Kabak, Erbaş, Cetinkaya, and Özceylan (2018) tried to evaluate the current status of bike-share stations in Izmir and locate future station sites by comparing them to existing stations. In this study, an assessment was made for existing bicycle sharing stations using the GIS-based multi-criteria decision method and new alternative stations were proposed. Proximity to the subway station, proximity sport centers, proximity to tourism/recreation area, and proximity to shopping malls are some criteria taken into account in this study.

Likewise, Özkan, Özceylan, and Sarıçiçek (2019) reviewed all scientific articles in GIS-based MCDM modeling for landfill site appropriateness analysis in academic journals. The study has been covered and reviewed in total of 106 studies published between 2005 and 2019. Criteria analysis concluded that distance to city areas, land use, geology, distance to fault zone, slope, and distance to road are the most common groups of criteria.

In the year of 2013, Sánchez-Lozano, Teruel-Solano, Soto-Elvira, and García-Cascales (2013) worked on evaluating the optimum placement of photovoltaic solar power plants. The study is based on a combination of Geographic Information System (GIS) and multi-criteria decision making (MCDM) methods. The study has been decided to be carried out in the area of Cartagena, southeastern Spain. The analysis and calculation of the weights of the factors used in the study were found with the help of the AHP method, and the evaluation of the alternatives according to the degree of adequacy was made with the TOPSIS method. At the end of the study, a suitable site analysis was performed for the region selected as the workspace.

Thananusak, Punnakitikashem, Tanthasith, and Kongarchapatara (2020) discussed the development of electric vehicle charging stations in Thailand between 2015 and 2020. This research aims to review the goals, strategies, and operations in electric vehicle charging and to review the key problems encountered in developing charging stations. First, it was seen that oil and gas companies, electricity state enterprises, green energy companies, start-ups, and automotive companies affected charging stations in Thailand. Secondly, the most important problem with expanding the charging network in Thailand has been found to be high investment costs and high electricity sales prices.

In their study, Boyacı and Şişman (2022) worked on site selection methods for a pandemic hospital in Atakum, a district of Samsun City, Turkey. The main purpose of this study is that COVID-19 poses many challenges for hospitals around the world, and Turkey is among the countries that are experiencing this problem. Problems in hospitals are tried to be solved with different methods, for example, it is aimed to open new pandemic hospitals in addition to the existing pandemic hospitals. As a solution to the problem, spatial analysis was first performed using GIS to create maps based on the seven criteria obtained. The criteria considered in the study are slope, distance to transportation network, population density, distance to industrial areas, land value, distance to existing hospitals, and distance to fire stations. In the study, the distance to the transportation network is the most important criterion affecting the selection process, and the least important is the distance to the fire stations. After calculating the criteria weights, 13 appropriate locations for a pandemic hospital were determined using GIS according to the criteria weights.

Another study that contributes to the field using GIS is the study of Greene, Devillers, Luther, and Eddy (2011). This study is a framework for GIS users, analysts and researchers to quickly improve the MCDA. The study provides an overview of the GIS with the background and methods of the MCDA. It is also mentioned that increasing the accessibility of GIS-based MCDA will provide new opportunities for researchers and practitioners.

Herlawati, Abdurachman, Heryadi, and Soeparno (2020) have studied in their study that GIS-based multi-criteria decision making can be used to cluster the area in urban regarding the central business. A classification is recommended for the Karawang district, Java, a small urban area with the potential to become a new central business district. Urbanization is a dynamic phenomenon, therefore, further analysis is needed in terms of the future sustainability of the study area. In this study, study was carried out considering the criteria far from risk areas, near to business centers, near to support facilities, near to main roads, near to residentials, and flat areas. After the Euclidean distance analysis, a reclassification map was created within six criteria, and these maps were used in the study to evaluate the suitable location for the central business.

Bilgilioglu, Gezgin, Orhan, and Karakus (2022) proposed a GIS-based MCDM method for the selection of potential municipal solid waste disposal sites in Mersin (a Turkish province). Eleven different criteria were taken into account in the study: distance from rivers and water surfaces, distance from roads, elevation, distance from settlements, distance from protected areas, slope, permeability, distance from lineaments, groundwater level, and land cover. The suitability of the locations of the nine existing municipal solid waste disposal sites has been assessed. Seven disposal sites have been decided to be unsuitable locations.

Abdelbaky, Peeters, and Dewulf (2021) tried to forecast the potential contribution of EV battery recycling to fulfilling the material needs of producing EV batteries over the next 20 years. In the study, it was concluded that for the recycling of electric vehicle batteries, investment in battery recycling capacity should be made in the next ten years. As a result of the forecasting model, the vehicle stock will be between 72 and 78 million vehicles by 2040, while the second stock of use will be between 3 and 11 million batteries. These forecasting results show that this waste stream could cover between 10% and 300% of future raw materials demand for EVs.

In the study of Kaya, Alemdar, Atalay, Çodur, and Tortum (2022), the GIS-based fuzzy MCDM method is offered for the solution of site selection problems of electric car-sharing stations. The study can be summarized in three steps: (i) determining 20 sub-criteria and weighting the criteria with fuzzy AHP, (ii) obtaining an appropriateness map for potential ECSS via GIS, and (iii) sorting the performance levels of electric car-sharing stations assigned according to the appropriateness map by Elimination and Choice Translating Reality. The study was conducted in Istanbul, and the study determined the suitable locations found on the Anatolian and the European side.

Ghorbanzadeh, Effati, Gilanifar, and Ozguven (2020) have worked on the GIS-based multi-criteria decision approach to select the best metro station locations. In the first step of this model, the suitability criteria and related sub-criteria are identified. Criteria such as population density, proximity to transit hubs, proximity to intersections, hospitals and medical centers, impact of earthquake faults, and historical places have been used. In the second step, the geographic information of each criterion is mapped using ArcGIS software. In the third step, Expert Choice software is applied to achieve the weight of criteria and candidate alternatives to implement AHP. Finally, it is sorted to determine the top five metro stations of ten potential areas in the workspace.

Using the GIS and MCDM method together, we have tried to find appropriate locations of EVCSs for the four districts selected in Istanbul. For this reason, it is estimated that this study will be a recommendation for battery station location selection and will contribute to the literature.

3. MATERIALS AND METHODS

3.1. Materials

In the present section, the materials utilized in the study such as the area where the study is applied, selection of criteria, map layers and resources, and the programs and software used are explained. 3 main and 8 sub-criteria have been determined for battery station location selection. Detailed explanations of these criteria are given in the criteria selection section. This study is carried out using the combination of MCDM and GIS techniques to find the appropriate locations of EVCSs. Detailed explanations about map layers, resources, programs, and software required for the integration of GIS and MCDM are given in the following subsections.

3.1.1. Application Area

First, the area in which the study is to be executed is determined. In this study, it was decided to carry out the study in Umraniye, Atasehir, Maltepe, and Kartal districts in the city of Istanbul. In fact, the main reason for the selection of a specific area in the city of Istanbul is because it is a very important city for Turkey in all respects. Throughout Istanbul's history, it serves as both a barrier and a bridge between the continent of Asia and the continent of Europe. For this reason, Istanbul has become the most populated city in our country. Since factors such as population, technological developments, and infrastructure affect the use of electric vehicles, it has been decided to study in a specific area of Istanbul.

Study Area (Istanbul, Turkey)

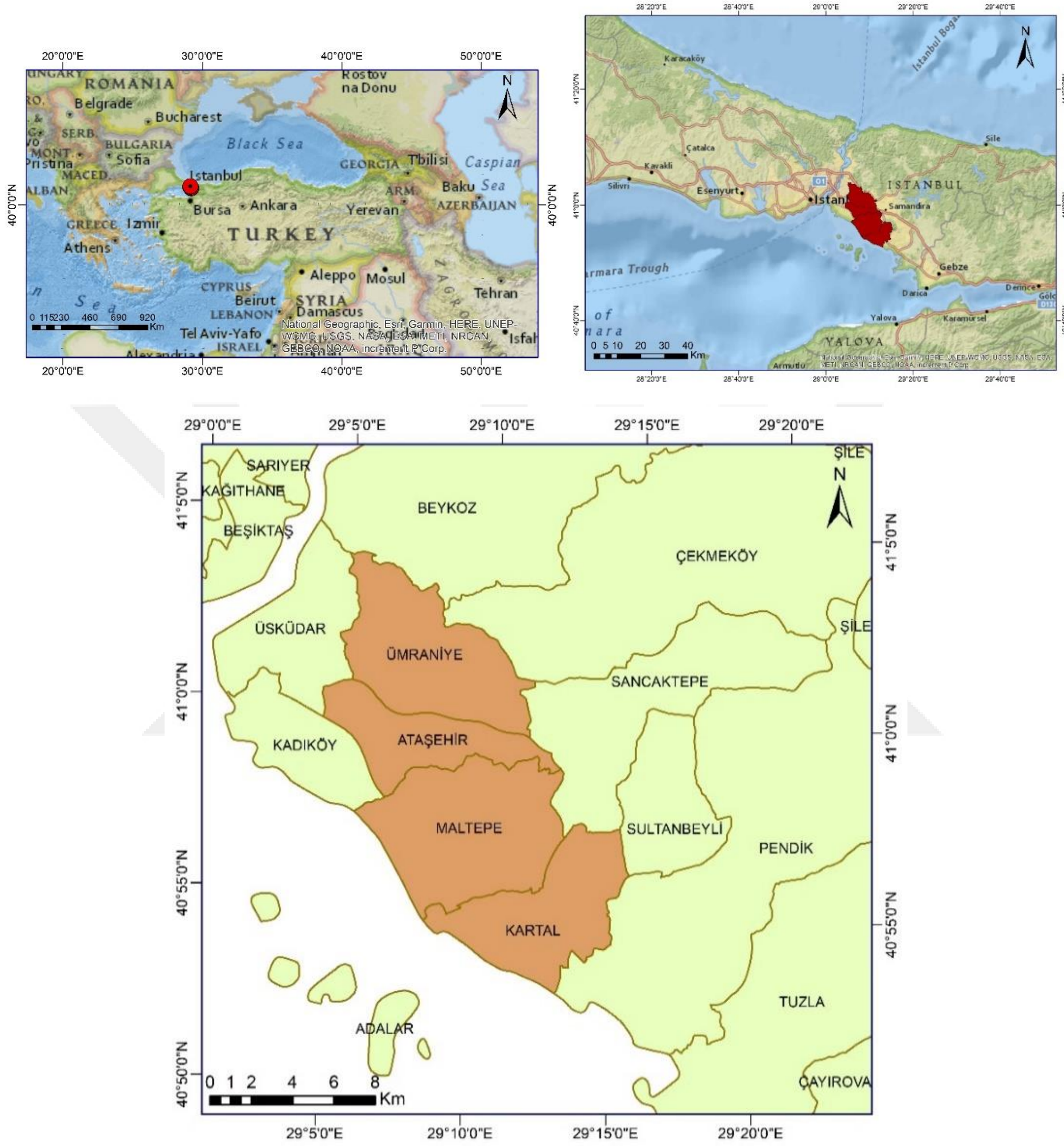

Figure 3. 1. Map of the area selected for the study.

3.1.2. Selection of Criteria

In order to achieve better and more accurate results in the study, it is very important to correctly decide on the criteria to be considered. Therefore, it is necessary to be very careful in selecting criteria. This section provides a detailed description of the criteria used in the study. In this study, eight sub-criteria have been used to select the proper locations of the EV charging stations. The selection of criteria that affect the location of the charging station has been taken into account in the research that exists in the literature. These criteria are slope, population density, park areas, petrol stations, shopping malls, roads, green areas, and land values. Figure 1 shows the AHP hierarchy of these criteria.

ACCESSIBILITY

Population density (C1): Charging stations are more needed in regions where EVs are widely used. Therefore, population density is often used as a factor to identify these regions. Locations with high population density are more proper for the vehicle charging station. In this study, the current population data of the Turkish Statistical Institute (TurkStat) is used. It is necessary to calculate and classify the population density for each district.

Shopping malls (C2): People spend long hours in shopping malls, these hours will give them time to recharge their vehicles. As shopping malls are useful for charging stations, it is considered a viable option to decide on the appropriate location for vehicle charging stations. Google Maps were used to find the malls within the workspace. First, the coordinates of the shopping centers were acquired, and later the coordinate system transformation was made. A charging station location is more suitable if it is close to the shopping mall.

Petrol Stations (C3): Petrol stations are one of the first convenient locations for electric vehicle charging stations. Internal combustion vehicles are known to have different station requirements than electric vehicles. However, because the petrol stations are located according to the current traffic network, the available petrol stations can be considered appropriate locations for EVCSs. If the location to be selected is close to the petrol station, it can be said that it is more proper for us.

Park Areas (C4): Parking areas are criteria taken into account for EVCSs because parked vehicles have an efficient charging time. Proximity to parking areas increases station location suitability. The parking areas data was obtained from Istanbul Metropolitan Municipality (IMM) open data portal. The map coordinate transformation of these obtained locations has been made and converted to available.

Roads (C5): Roads frequently used by cars and other vehicles are critical to determining the suitable locations of the EVCSs. Locations near the road are preferred for the battery station, this preferred station location is more suitable.

ENVIRONMENTAL

Green Areas (C6): Green areas are considered the environmental factor when finding the appropriate locations for the EVCSs. It is preferable to have the battery station location away from the green areas.

ECONOMIC

Land values (C7): Land value is a factor often considered for the appropriate location selection of EV charging stations. The reason it is considered a factor is that the study areas are regions with very variable land values. Locations with low land values are more appropriate for us. The average annual land value is taken into account.

Slope (C8): Slope is a factor that is considered for almost all studies. The percentage of the slope is expected to be low where the battery stations are installed, as construction costs are high on high slopes. If the slope value of the location is low, it is considered more proper for the station location and the construction cost is low.

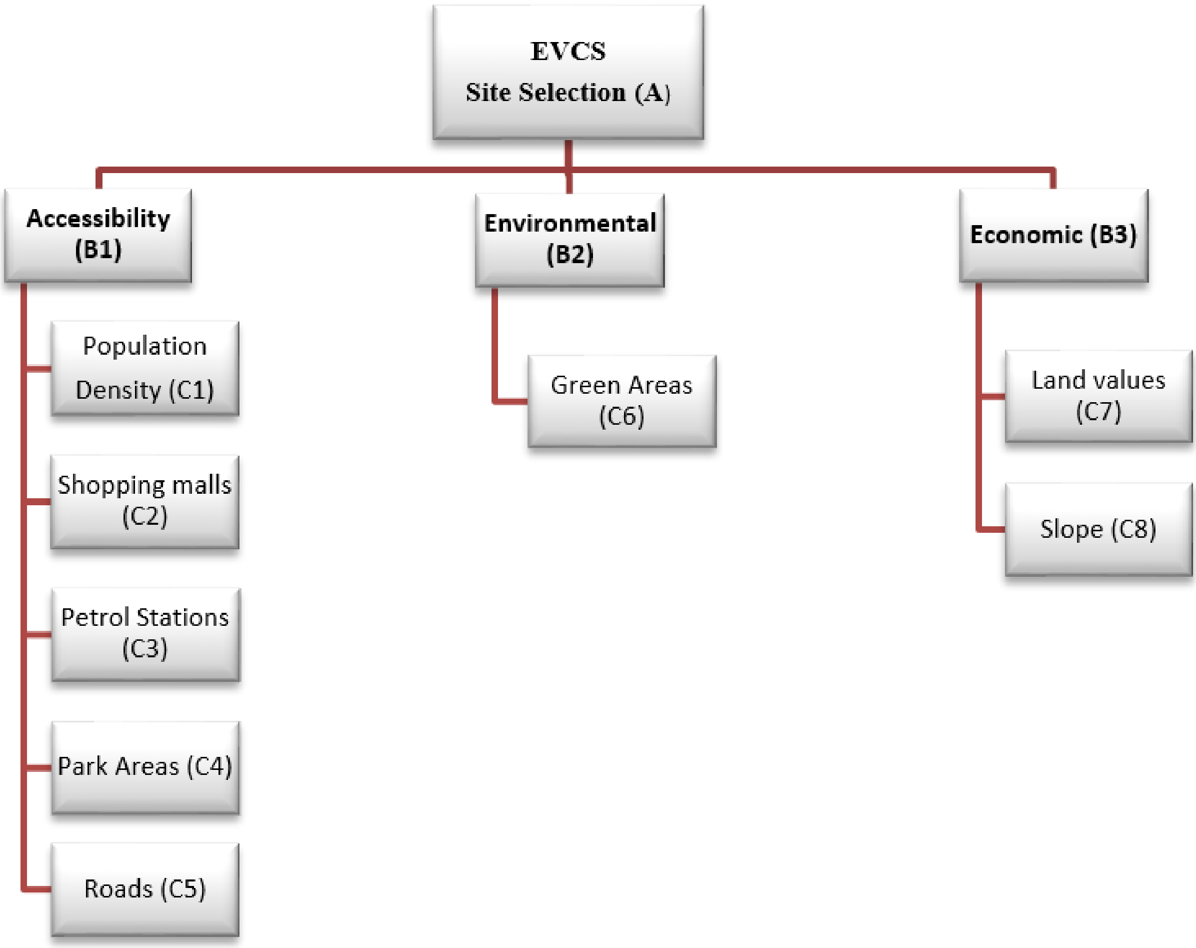

Figure 3. 2. AHP hierarchy of the study.

This section provides a comprehensive description of each criterion and sub-criteria, and Table 3.1 lists the scores for these sub-criteria.

Table 3. 1. Criterion scores.

Criterion	Sub-Criterion	Score
Population density (C1)	16.000<	5
	14.000-16.000	4
	12.000-14.000	3
	10.000-12.000	2
	<10.000	1
Shopping malls (C2) (m)	<250	5
	250-500	4
	500-750	3
	750-1000	2
	1000<	1
Petrol stations (C3) (m)	<250	5
	250-500	4
	500-750	3
	750-1000	2
	1000<	1
Park areas (C4) (m)	<250	5
	250-500	4
	500-750	3
	750-1000	2
	1000<	1
Roads (C5) (m)	<250	5
	250-500	4
	500-750	3
	750-1000	2
	1000<	1
Green areas (C6) (m)	250<	5
	200-250	4
	150-200	3
	100-150	2
	<100	1
Land values (C7) ₺/m^2	<4000	5
	4000-4500	4
	4500-5000	3
	5000-5500	2
	5500<	1
Slope (C8) (°)	<5	5
	5-10	4
	10-15	3
	15-20	2
	20<	1

3.1.3. Map Layers and Resources

In the current study, the data layers of the chosen criteria are required to perform the analysis using the GIS technique. A separate map layer is created for each sub-criterion, downloaded from open sources or drawn according to existing data or coordinates. In other words, geospatial data, such as existing roads, has been downloaded online and the layer has been created. Other map layers are created using existing coordinates or other numeric data.

The GIS data layers used in the study are shown in Figure 3.3. GIS datasets used in the study (population density, shopping malls, petrol stations, park areas, roads, green areas, land values, slope) are obtained from various sources as shown in Table 3.2.

The steps applied for the map layers in the analysis process using the Arcgis program are given in Figure 3.4.

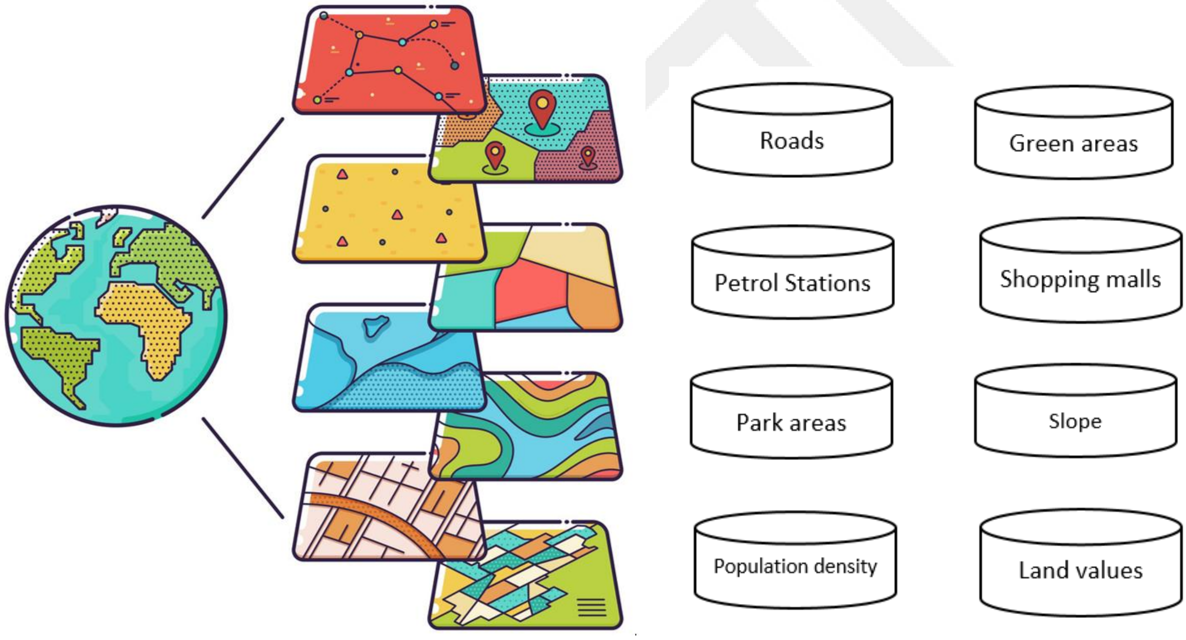

Figure 3. 3. GIS datasets used in the study.

Table 3. 2. List of data sources for criteria layers used in the study.

Sub-Criteria	Data Source
Population density (C1)	https://biruni.tuik.gov.tr
Shopping malls (C2)	https://www.openstreetmap.org
Petrol stations (C3)	https://www.openstreetmap.org
Park areas (C4)	https://www.openstreetmap.org
Roads (C5)	https://www.openstreetmap.org
Green areas (C6)	https://www.openstreetmap.org
Land values (C7)	https://www.endeksa.com/tr
Slope (C8)	https://earthexplorer.usgs.gov

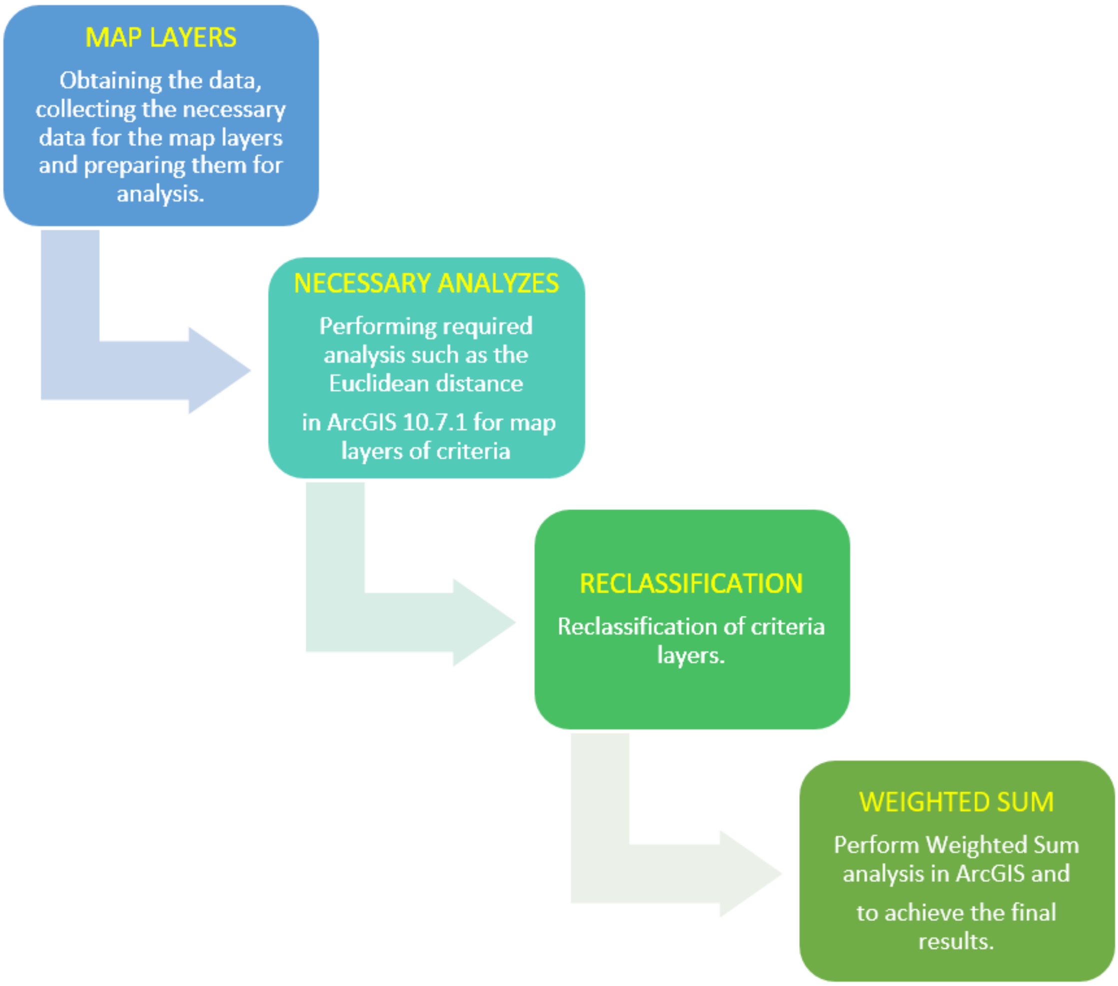

Figure 3. 4. General steps applied for the map layers in the analysis process using the ArcGIS program.

3.1.4. Programs and Softwares

ArcGIS is one of the most popular software among commercial software programs developed to perform spatial analysis for site appropriateness analysis. ArcGIS is a scalable integrated Geographic Information System software developed by ESRI. In the current study, ArcGIS 10.7.1 software is used to create map data, create data sets, and perform specific analysis with the help of data sets. The Online Output Software is used to calculate the AHP weights of the criteria. ArcGIS and other necessary programs and software were used in the study.

3.2. Methods

In this section, the methods used in the study were tried to be explained. The AHP method used to weigh the criteria in the study is detailed in the following subsections. In addition, the GIS-based MCDM Method used for the analysis of the study is detailed in the following subsections.

3.2.1. Multi-Criteria Decision Making Method

People face decision-making in many areas of their lives, which are often complicated because they include many criteria. Therefore, the MCDM method has been developed, which supports decision-making mechanisms in unique and personal decision-making processes. MCDM method enables a more logical and scientifically defensible decision to be made. MCDM methods have attracted the attention of decision-makers in planning and solution of complicated projects that have many criteria in recent years. Decision makers use these methods to consider many criteria and create alternatives to obtain the best solution.

Some of the most used MCDM methods are given below;

- ANP
- FAHP
- AHP
- TOPSIS
- ELECTRE
- VIKOR
- PROMETHEE

MCDM problems are often divided into two classes, continuous and separate. Multi-Objective Decision Making (MODM) methods are used to handle continuous problems. On the other hand, Multi-Attribute Decision Making (MADM) methods are used to handle separate problems (Rezaei, 2015).

MCDM is a useful tool that plays an important role in the fields of investment decisions, economic benefit evaluation, project evaluation, etc. Some studies conducted with this tool include financial risk analysis, supplier evaluation, strategic vendor selection, planning, and design tenders selection in public office buildings, selection in healthcare industries, etc. (Gavade, 2014).

3.2.2. Analytic Hierarchy Process (AHP)

AHP is a method that assists to deal with complex problems and solve them. The method developed by Saaty has made significant progress over the years. AHP makes the decision-making process using the required criteria. AHP first identifies the criteria required for the decision-making process and then performs the analysis using these criteria. Starting with the general purpose, the rankings of the criteria and sub-criteria are obtained, and the alternatives are determined to create a hierarchical structure. When creating pairwise comparison matrices, decision makers determine how important a criterion is compared to another criterion. The purpose of creating matrices is to convert the preferences of decision makers to a computable scale (Saaty, 1990). This conversion is made using specific scales. These scales are shown in Table 3.3.

Table 3. 3. Fundamental scale for pairwise comparison in AHP.

Verbal Scale	Numerical Values
Equally Important	1
Moderately Important	3
Strongly Important	5
Very Strongly Important	7
Extremely More Important	9
Intermediate values to reflect compromise	2,4,6,8

The AHP method consists of some application phases, which are as follows.

Step 1: Creation of Criteria and Hierarchical Structure

First, the goal must be set correctly, after determining the goal, it is essential to create a hierarchical structure for criteria and alternatives. It is very important to create the hierarchical structure correctly because it will affect the decision making mechanism. The basic hierarchical structure of the AHP is shown in Figure 3.5.

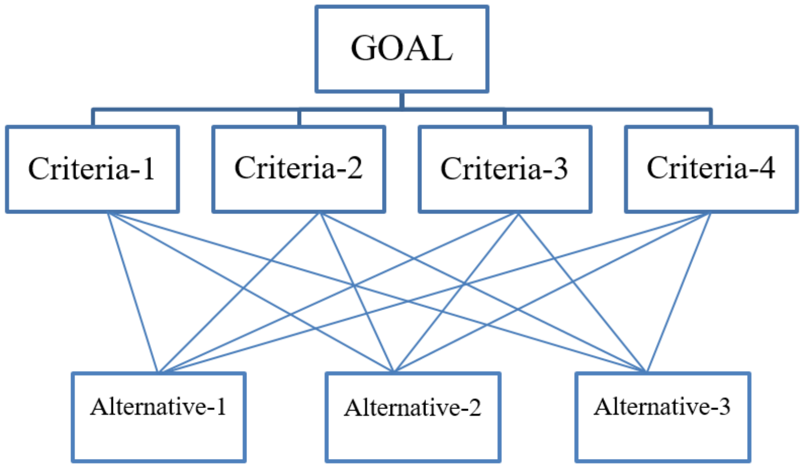

Figure 3. 5. General hierarchical structure of AHP.

Step 2: Creating the Pairwise Comparison Matrix

Once the hierarchy structure has been established, it is necessary to evaluate both criteria and alternatives among themselves. A pairwise comparison matrix is created to determine the significance scales between the criteria and the sub-criteria. The comparison matrix is shaped based on the decision maker's decisions. The pairwise comparison matrix for the sub-criteria of the accessibility main criteria is shown in Figure 3.6.

Table 1: Pairwise comparison with respect to Accessibility(B1)

	Population d...	Shopping malls	Petrol stations	Park areas	Roads
Population density		0.5	0.5	0.5	0.5
Shopping malls			0.5	2	0.333333333
Petrol stations				2	0.5
Park areas					0.5
Roads					

Figure 3. 6. The pairwise comparison matrix for the sub-criteria of the accessibility.

Step 3: Normalization of the Pairwise Comparison Matrix

First, each value in the matrix is divided into the sum of the column to create a normalized comparison matrix. The average values of each row of this second matrix are determined and thus the criteria weights are obtained.

Step 4: Calculation of the Consistency Ratio (CR)

The consistency rate is calculated for each dual comparison matrix and the recommended high limit for this ratio is 0.10. The judgments are consistent if the calculated consistency ratio is calculated at a value less than 0.10. If a value greater than this value is calculated, the judgments are inconsistent.

This step first calculates a list of the relative weights, importance, or value of the factors associated with that problem. In fact, this list is technically called an eigenvector. Consistency is determined by using the eigenvalue (λ) to calculate the consistency index (CI).

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n} \tag{1}$$

In this step, the consistency of the comparison matrix is calculated. The Consistency Index value must be calculated to determine if the matrix generated by the comparison is consistent.

In AHP, the consistency of the comparison matrix is measured by the following consistency index.

$$\boldsymbol{CI} = \frac{\boldsymbol{\lambda} - \boldsymbol{n}}{\boldsymbol{n} - \mathbf{1}} \tag{2}$$

In addition, the random index (RI) value must be known to assess consistency. Table 3.4 gives the corresponding random index value for each matrix size n.

Table 3. 4. Random Inconsistency Index (RI).

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56	1.57	1.59

Once the RI and CI values are calculated and determined, the Consistency Ratio (CR) is calculated.

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}} \tag{3}$$

The value of the CR less than 0.10 denotes that the comparisons are consistent. When the CR value is bigger than 0.10, there is a calculation error or the pairwise comparisons are inconsistent. When faced with this type of situation, the comparisons will review again.

AHP method is utilized to find the most convenient solution for diverse problems such as site selection, choice of technology, economy, medicine, supplier selection, finance, and marketing. The AHP method has been selected because it is very useful for the location selection of the battery stations of electric vehicles.

3.2.3. Geographic Information Systems (GIS)

The origin of GIS is based on the implementation of computer graphics in various areas, such as city planning, land management, and geographical coding in 1960 and 1970. Commercial GIS applications began to emerge in 1970, and ESRI is one of the best companies that produce applications. In 1990, GIS continued to develop through personal computing. Today, GIS has become one of the most intriguing and promising high-tech fields (Wieczorek & Delmerico, 2009).

Geographic Information System is a computer system used to capture, store, query, analyze and display large volumes of geographic data for a particular purpose. Geospatial data defines the location and the attributes of spatial features (Chang, 2016).

Many different types of information can be compared, edited, and visualized using GIS. The system can include data such as education level, population, the location of streams, income, factories, farms, schools, roads, and electric power lines. Geographic Information Systems are powerful decision-making tools for any industry or business. Because GIS allows the analyzation of topographic, demographic, and environmental data. GIS applications help companies, industries and consumers make informed decisions. Some of the most widely used industry and business areas of geographic information systems are banking, supply chain management, health and human services, forestry and timber, urban planning, insurance, accident analysis, hot spot analysis, environmental impact analysis, etc.

Some of the most used GIS software around the world:

- ArcGIS Pro
- ArcGIS Desktop
- QGIS
- MapInfo Professional
- Google Maps API
- Whitebox GAT
- OpenStreetMap
- Maptitude

The GIS software allows people to create their own digital map layers to help solve real-world problems. GIS has also become a tool for data sharing and collaboration. In today's modern world, hundreds of thousands of organizations create billions of maps and share their work every day to tell stories and reveal models, trends, and relationships related to everything.

3.2.4. GIS-Based Multi-Criteria Decision Making Method

GIS-based MCDM can be defined as a process that converts and integrates spatial data and the decision maker's preferences. The integration of GIS and MCDM has attracted significant interest in the last 30 years. The combination of GIS and MCDM continues to be implemented by experts and academia until today. The GIS-based MCDM method helps us choose from different alternatives based on various criteria or selection factors and deal with complex decisions. Criteria analysis shows that land use, surface and ground water, transportation stations, green areas, land values, population density, distance to urban areas, distance to road, slope, and geology are the most common criteria groups (Özkan et al., 2019).

GIS-MCDM has been utilized in countless studies such as urban planning, site suitability analysis, urban infrastructure, assessment of solar and wind farm locations, etc. The GIS-based MCDM method has essential advantages like the exploration of potential and current fields, attaining more exact and controlled results by narrowing the target field, and preparing data spread over large areas (Sánchez-Lozano et al., 2013).

Some examples of studies made using the GIS-based MCDM method:

- Finding suitable locations for wind farms, and solar farms.
- Pandemic hospital site selection.
- Evaluation of groundwater potential.
- Evaluation of Central Business suitability.
- Flood risk analysis.
- Site selection of fire stations.

3.2.4.1. Site Selection with GIS-Based MCDM Analysis

Some procedures should be handled by GIS in order to acquire better results in the current study. The ArcGIS program is a scalable integrated GIS software developed by ESRI, which helps us solve problems with GIS. All criteria data and other data to be used must be processed using different modules of the ArcGIS software. ArcGIS 10.7.1 software is utilized to generate data sets, generate map data, and perform certain analyzes with the help of data sets. Figure 3.7 shows the general diagram of the current study and the steps of the analysis procedures. The analysis types utilized in the ArcGIS software are reviewed under the following titles.

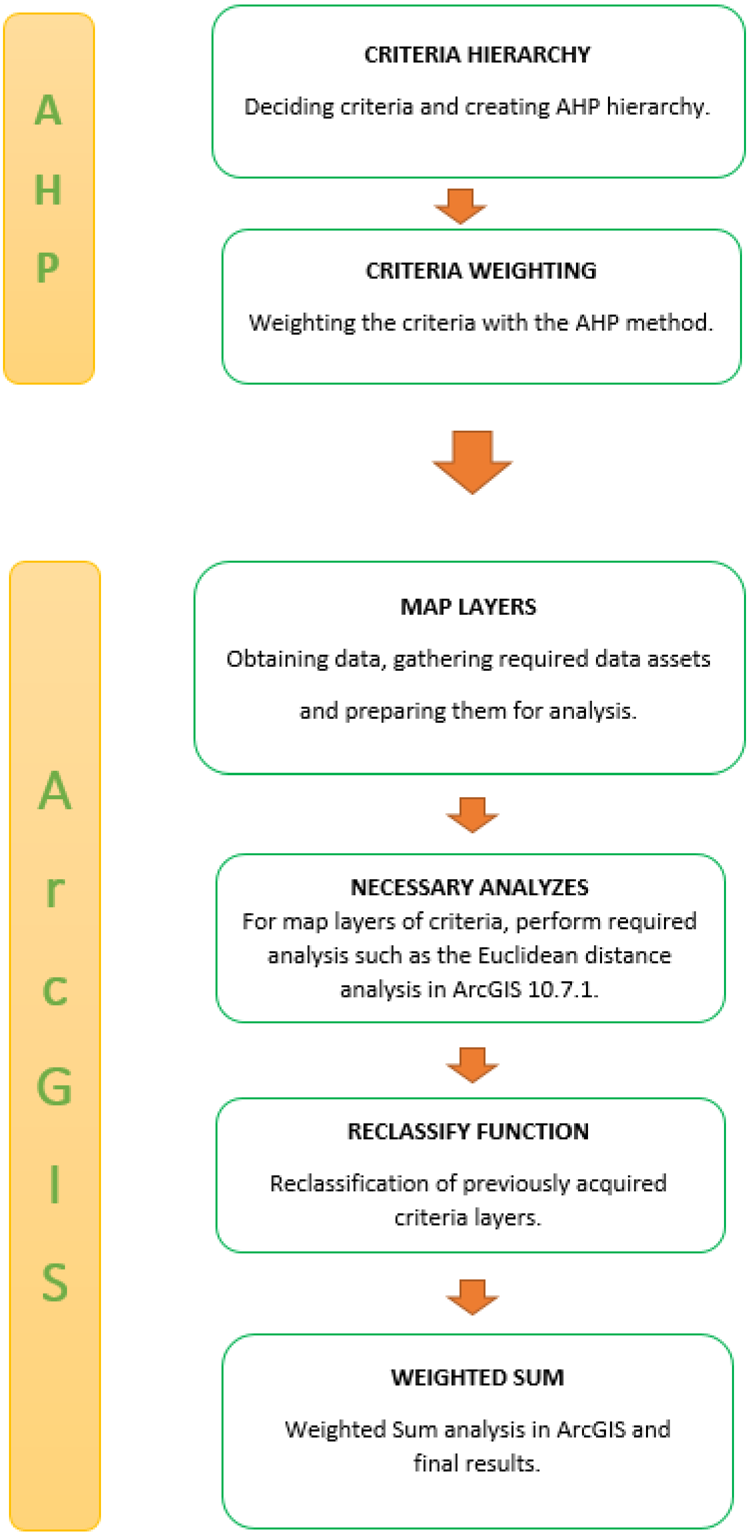

Figure 3. 7. General diagram of the current study and steps of the analysis procedures.

3.2.4.1.1. Euclidean Distance

Euclidean distance is one of the primary ways to perform distance analysis at ArcGIS Spatial Analyst. Euclidean distance functions measure the straight line distance from each cell to the nearest source, it can not only determine the allocation but also calculate the distance and direction to the nearest source. Euclidean distance output raster contains the measured distance from each cell to the closest source. Distances are measured as crow flies (Euclidean distance) in raster projection units such as meters and calculated from cell center to cell center. Some examples can be given such as distance to school, distance to roads, and distance to hospitals, for which distance analysis was made by Euclidean Distance analysis.

Some sub-criteria in the study depends on the proximity or distance to the selection field. Based on former site selection studies available in the literature, distance-based scoring maps are generated with ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance tool. Euclidean distance analysis has been performed for Green areas, Park areas, Shopping malls, Petrol stations, and Roads criteria.

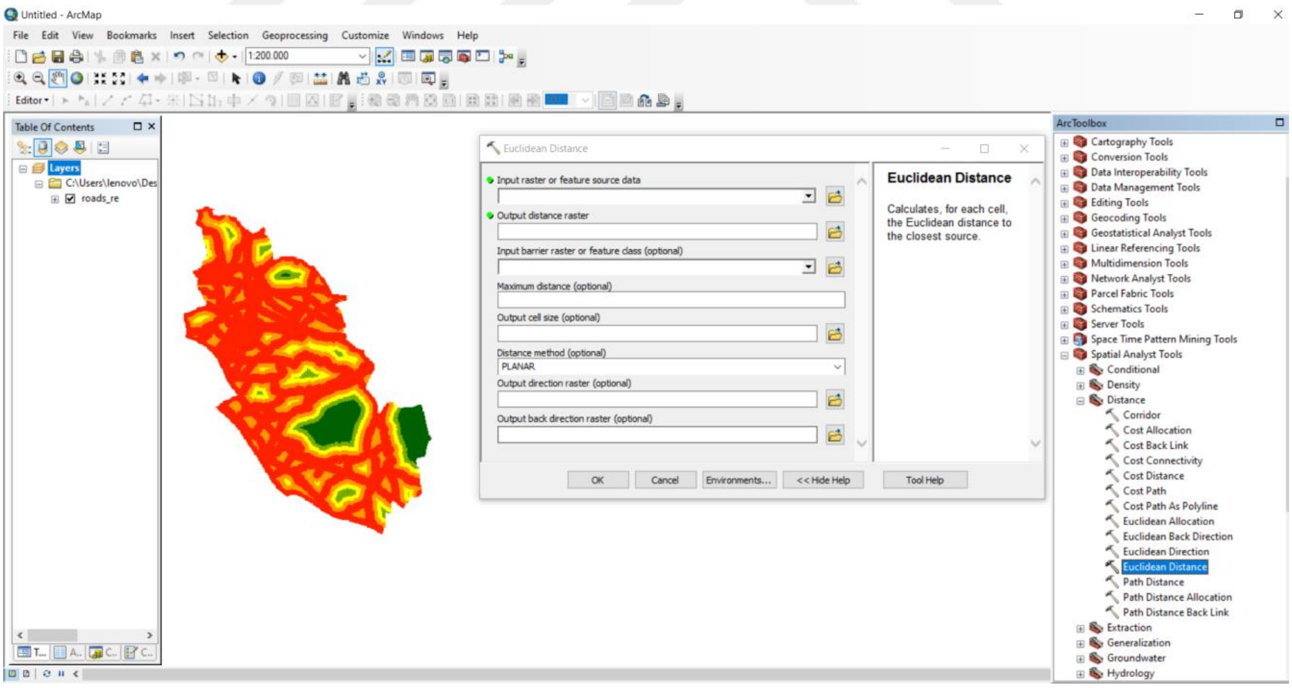

Figure 3. 8. Euclidean Distance’s function output.

3.2.4.1.2. Kernel Density

The Kernel Density tool, used for the population density criterion, calculates the density of features in a neighborhood around those features. Possible uses include analyzing the density of housing or occurrences of crime for community planning purposes or exploring how traffic accidents or an epidemic have affected the area. The population density map is created ArcToolbox > Spatial Analyst Tools > Density > Kernel density tool.

3.2.4.1.3. Inverse Distance Weighted (IDW)

The Inverse Distance Weighting interpolator assumes that each entry point has a local effect that decreases with distance. That is, it weighs points closer to the processing cell more than those farther away. The use of this method assumes that the effect of the mapped variable declines with distance from its sampled position. Inverse Distance Weighted (IDW) interpolation allows mapping of climate and temperature indicators, rainfall, or elevation in specific areas. The Land values map is created ArcToolbox> Spatial Analyst Tools> Interpolation> IDW tool.

3.2.4.1.4. Reclassification

Reclassification is the action or process of classifying something or a new, that is, reassigning one or more values in a raster dataset to new output values. The Unique or Classify options in the Reclassification parameter allows us to generate a remap table based on the values of the input raster. Reclassification analysis has been performed for all criteria used in the study. All reclassified maps are generated via ArcToolbox > Spatial Analyst Tools > Reclass > Reclassify tool. As an example of reclassification, the reclassification for the Roads criterion is given in Figure 3.9.

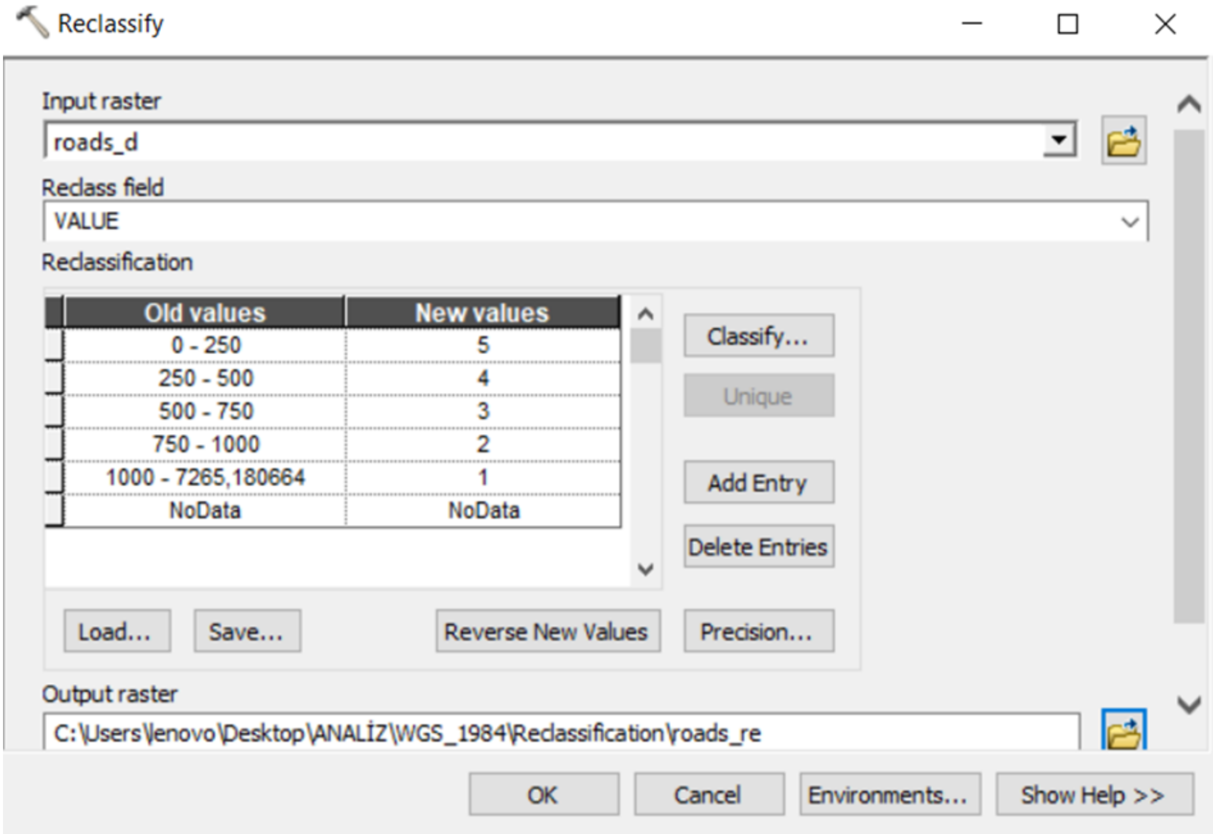

Figure 3. 9. Dialog window of Reclassification for Roads criterion.

3.2.4.1.5. Weighted Sum Analysis

Weighted sum analysis is a useful way to add several rasters together, multiple rasters are entered and all weights are equal to 1. The Weighted Sum tool enables weighting and combining multiple inputs to create an integrated analysis. In this way, multiple raster inputs representing multiple factors can be easily combined by including weights or relative importance. The dialog window of the Weighted Sum function is shown in Figure 3.10.

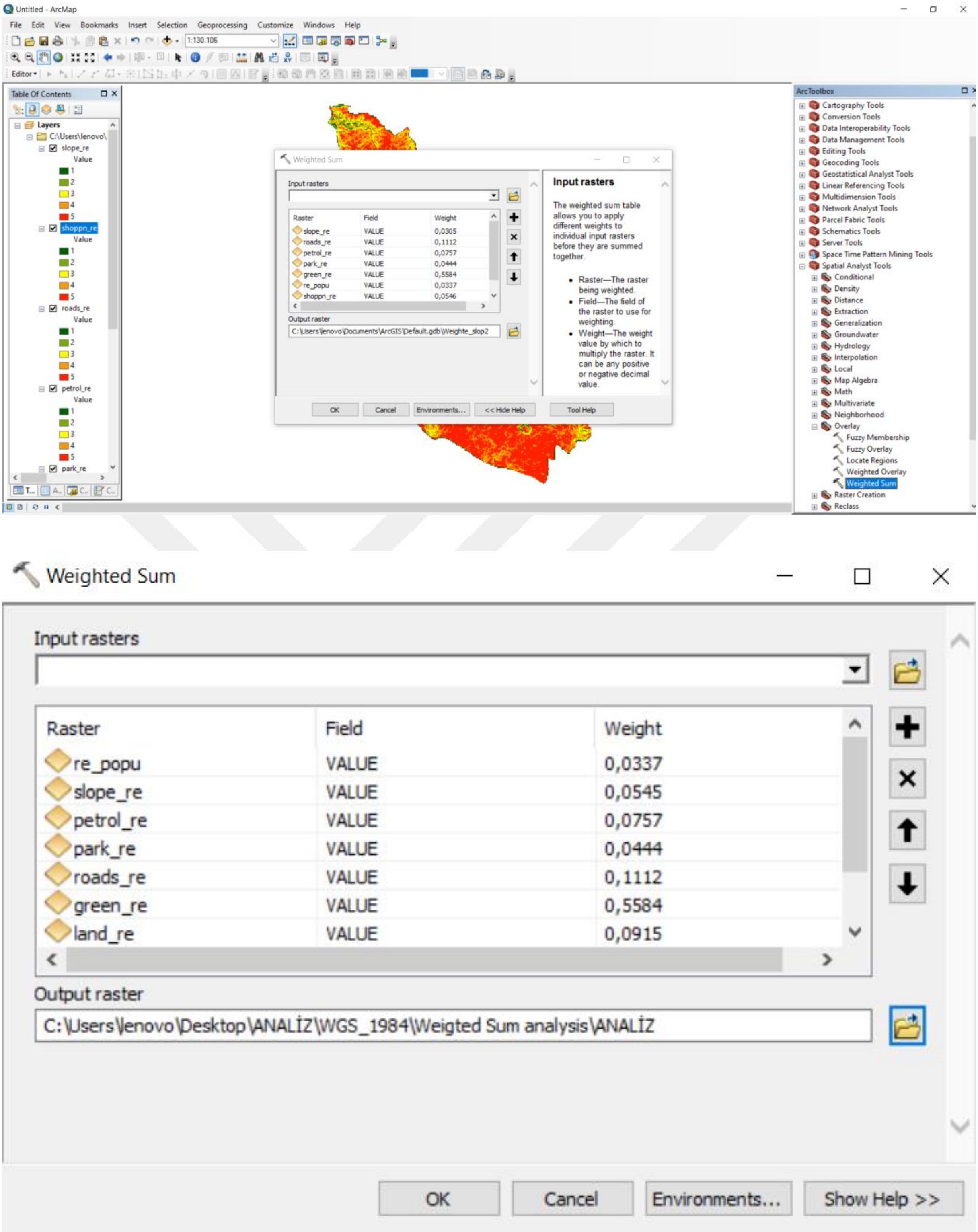

Figure 3. 10. Dialog window of Weighted Sum Analysis.

4. RESULTS AND DISCUSSIONS

4.1. Determination of the Priorities by Using AHP

This study has been carried out in accordance with various criteria, and these criteria weights are determined using the AHP methodology. In this sense, firstly the pairwise comparison matrix is created separately, and then the criteria weights are calculated by the AHP methodology. The pairwise comparison matrix of accessibility, environmental, and economic criteria is seen in Table 4.1. In addition, the comparison matrix of the accessibility sub-criteria can be seen in Table 4.2.

Table 4. 1. Pairwise comparison matrix for main criteria.

A	B1	B2	B3	W
B1	1	1/2	3	0,3196
B2	2	1	4	0,5584
B3	1/3	1/4	1	0,1220

B1: Accessibility, B2: Environmental, B3: Economic

Table 4. 2. Pairwise comparison matrix for accessibility subcriteria.

B1	C1	C2	C3	C4	C5	W
C1	1	1/2	1/2	1/2	1/2	0,1055
C2	2	1	1/2	2	1/3	0,1707
C3	2	2	1	2	1/2	0,2369
C4	2	1/2	1/2	1	1/2	0,1389
C5	2	3	2	2	1	0,3480

C1: Population density, C2: Shopping malls, C3: Petrol stations, C4:Park areas, C5: Roads

Another pairwise comparison matrix for economic sub-criteria is given in Table 4.3. All sub-criteria weights utilized in this study are given in Table 4.4.

Table 4. 3. Pairwise comparisons matrix of economic sub-criteria.

B3	C7	C8	W
C7	1	3	0,75
C8	1/3	1	0,25

C7:Land values, C8:Slope

Table 4. 4. Weights of all sub-criteria.

Goal A	Hierarchy B	Hierarchy C	W
A	B1	C1	0,0337
		C2	0,0546
		C3	0,0757
		C4	0,0444
		C5	0,1112
	B2	C6	0,5584
	B3	C7	0,0915
		C8	0,0305

C1: Population density, C2: Shopping malls, C3: Petrol stations, C4:Park areas, C5: Roads, C6: Green areas, C7:Land values, C8:Slope

When the Consistency Ratio value is larger than 0.10, the pairwise comparisons are inconsistent or can be said to be a calculation error, in which case it is known that comparisons must be reviewed again. This means that the CR value less than 0.10 is consistent and we want the values to be within this range. The CR value is calculated as 0.018 for the main criteria B1, B2, and B3. The CR value is calculated as 0.054 for the sub-criteria C1, C2, C3, C4, and C5. For sub-criteria C7 and C8, the CR value is obtained as zero. When CR values are reviewed in our AHP results, all values are calculated to be less than 0.10. In this case, the values are determined to be suitable for analysis. Because the values are obtained as desired, there is no need to review the comparisons again.

4.2. Identification of Suitable Locations

The GIS-based MCDM approach is used to apply the model described in the methodology section to determine the convenient locations of the EVCSs. It is known that the suitability of charging stations differs according to distinct criteria. These criteria are decided and the criteria data and maps required for the study are collected. First, the obtained data and maps are integrated and the criteria are transformed into map layers. Certain analyzes such as IDW and Euclidean distance have been made for these map layers. A reclassification is performed for these map layers that have been analyzed. Then, these layers, which are ready for weighted sum analysis, are entered into the Arcgis program with their current AHP weights. The results maps of the weighted sum analysis of the study are detailed, thus making it visually richer and more understandable.

In the suitability maps, red-colored areas are defined as the most suitable, and green-colored areas are defined as the most unsuitable. Suitability decreases from red-colored areas to green-colored areas. The suitability maps for all criteria used in the study are given in the following sections with their description and interpretation. The fields available on the suitability maps of all criteria are divided into five categories; very suitable, suitable, acceptable, unsuitable, and very unsuitable areas. The article of Guler and Yomralioglu (2020) is taken as a reference in determining the criteria categories of Green areas, Park areas, Shopping malls, Petrol stations, Slope, and Roads sub-criteria. The categories of Population density and Land values sub-criteria are determined by dividing the criterion value into 5 numerically appropriate classes.

Fields, where electric vehicles are heavily utilized, require more charging stations, so locations with high population density are more convenient for a vehicle charging station. When the population density suitability map is examined, it is understood that the districts in which the population density is highest are Umraniye and Atasehir (Figure 4.1). The district with the lowest population density is Maltepe, it can be said that this district has more green areas. Kartal, on the other hand, is at an acceptable level.

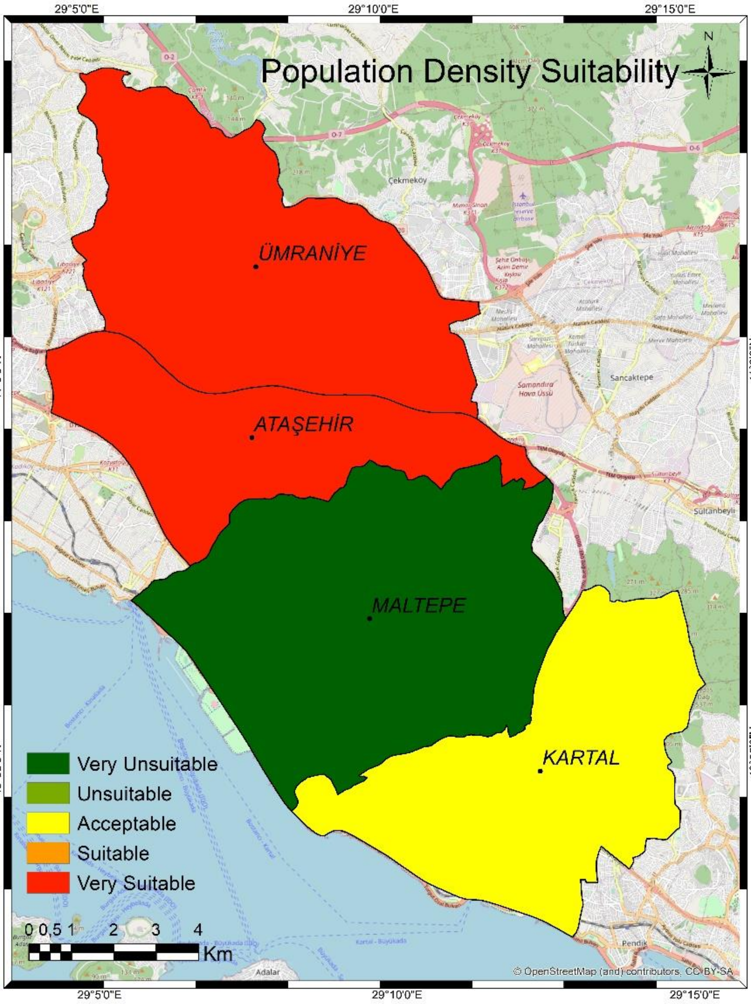

Figure 4. 1. Suitability map for the population density criterion.

People have enough time to recharge their vehicles while shopping in shopping malls. When the existing EVCSs are examined, it is known that some of them are located in shopping malls. The shopping malls suitability map has been examined, and it is seen that the district with the least number of shopping malls is Kartal (Figure 4.2). Atasehir is the smallest district compared to other districts, but the district has the most shopping malls. A large number of shopping malls will provide an advantage in terms of suitability for opening a charging station in the region. Therefore, Atasehir and Umraniye are the most advantageous districts in terms of the shopping mall.

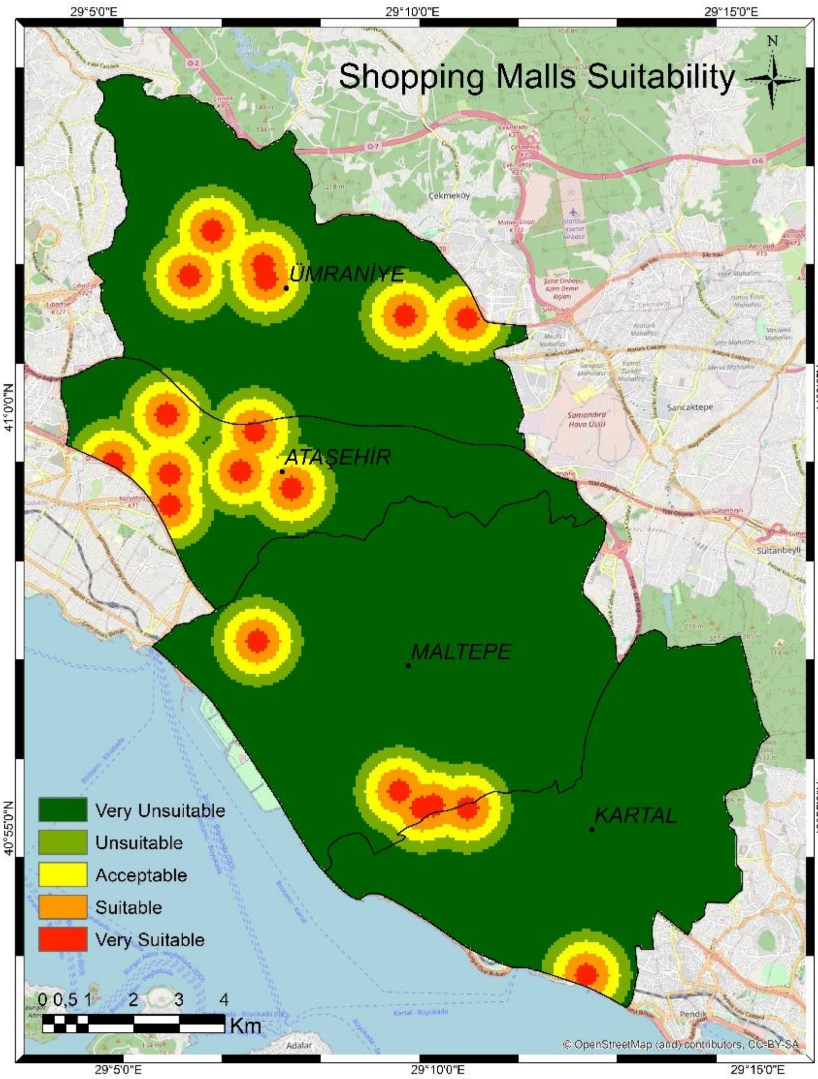

Figure 4. 2. Suitability map for the shopping malls criterion.

Petrol stations are one of the most suitable places for EVCSs, as petrol stations are located according to the existing traffic network and are usually close to the roads, for this reason, existing gas stations are proper locations for EVCSs. The suitability map for petrol stations is given in Figure 4.3. The reason why petrol stations are seen densely in some places in the study area is that there are many roads in these places. Especially in the green areas of Maltepe and Kartal, there are almost no petrol stations.

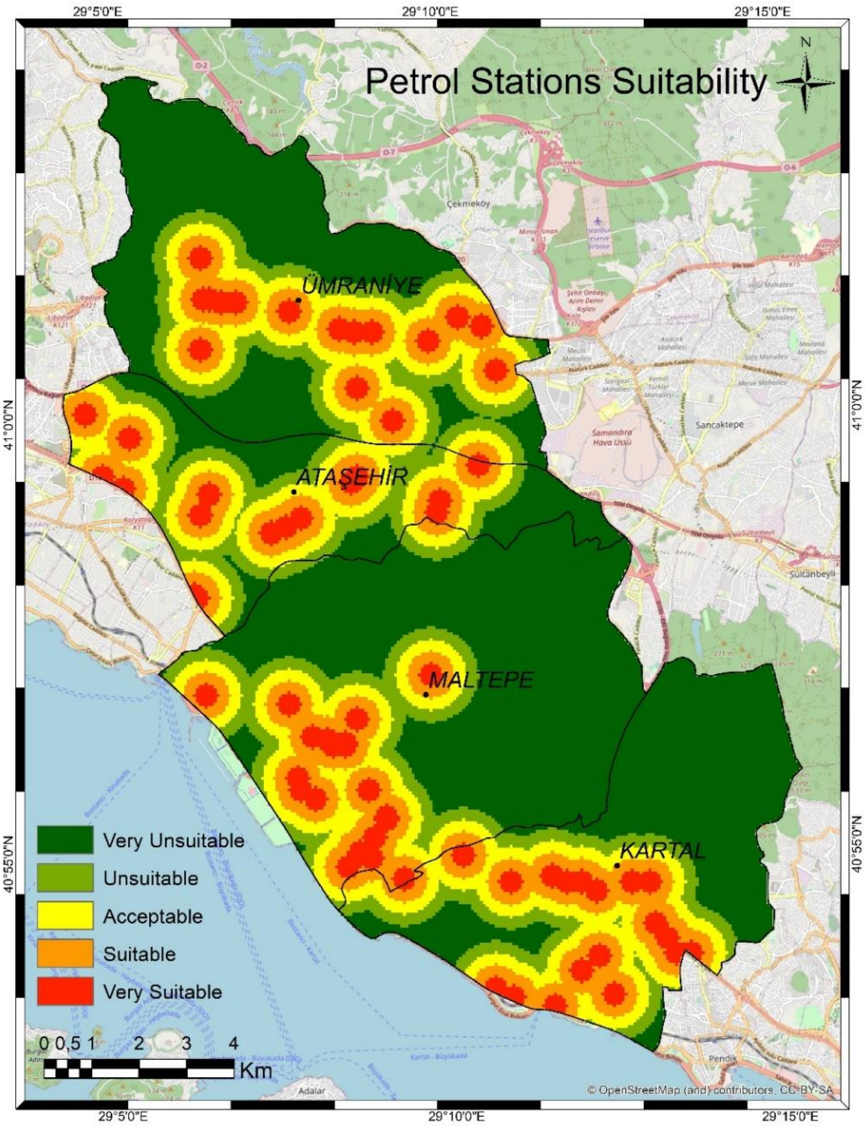

Figure 4. 3. Suitability map for the petrol stations criterion.

Parking areas are important places for the installation of electric vehicle charging stations, as parked vehicles have an efficient charging time. When people park their vehicles for a specific purpose, the car has a convenient time to recharge while waiting in the park. It can be seen when looking at the park areas suitability map that the parking areas are concentrated in some parts of the districts (Figure 4.4).

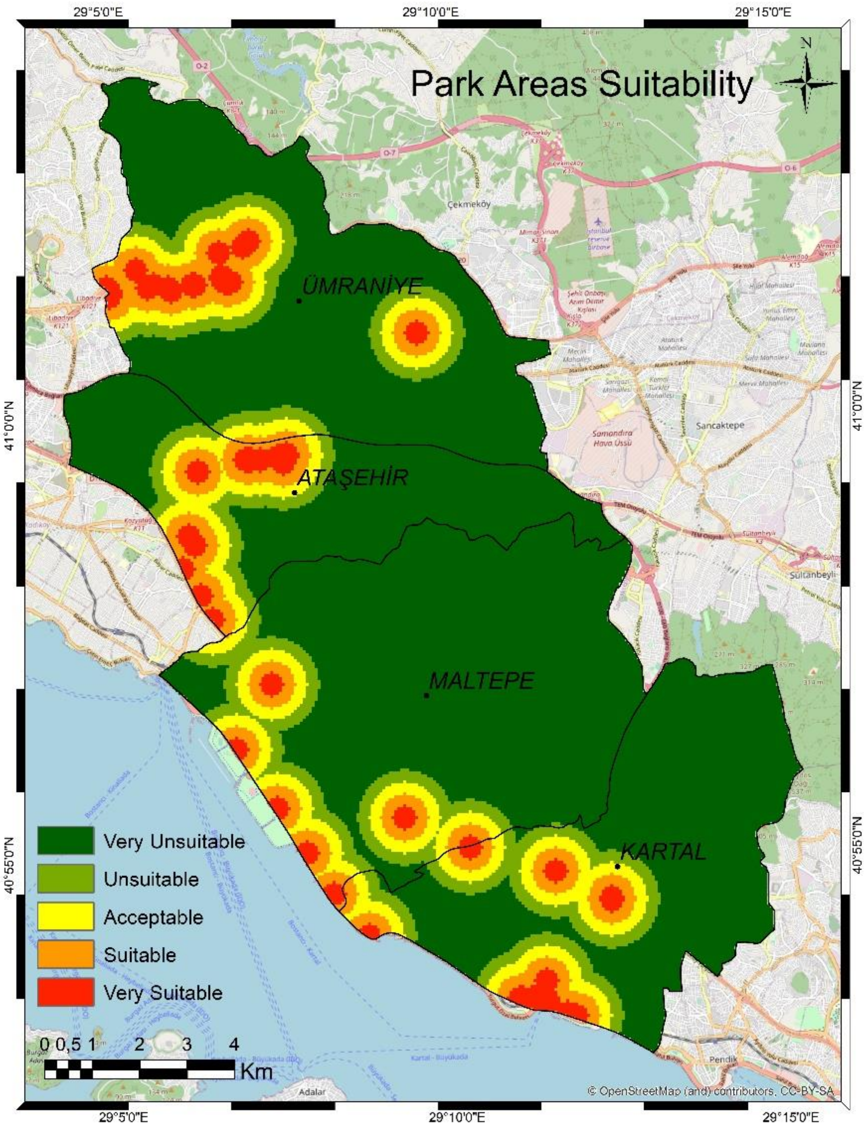

Figure 4. 4. Suitability map for the parking areas criterion.

Especially in metropolitan cities like Istanbul, a certain hour of a day passes on the roads to reach from one place to another. With the increase in the use of private vehicles, the density and use of roads increases. Roads which are frequently utilized by vehicles are important in determining the appropriate locations of EVCSs. The suitability map for roads is given in Figure 4.5. Except for some parts of Maltepe and Kartal districts, road density is high in the entire study area.

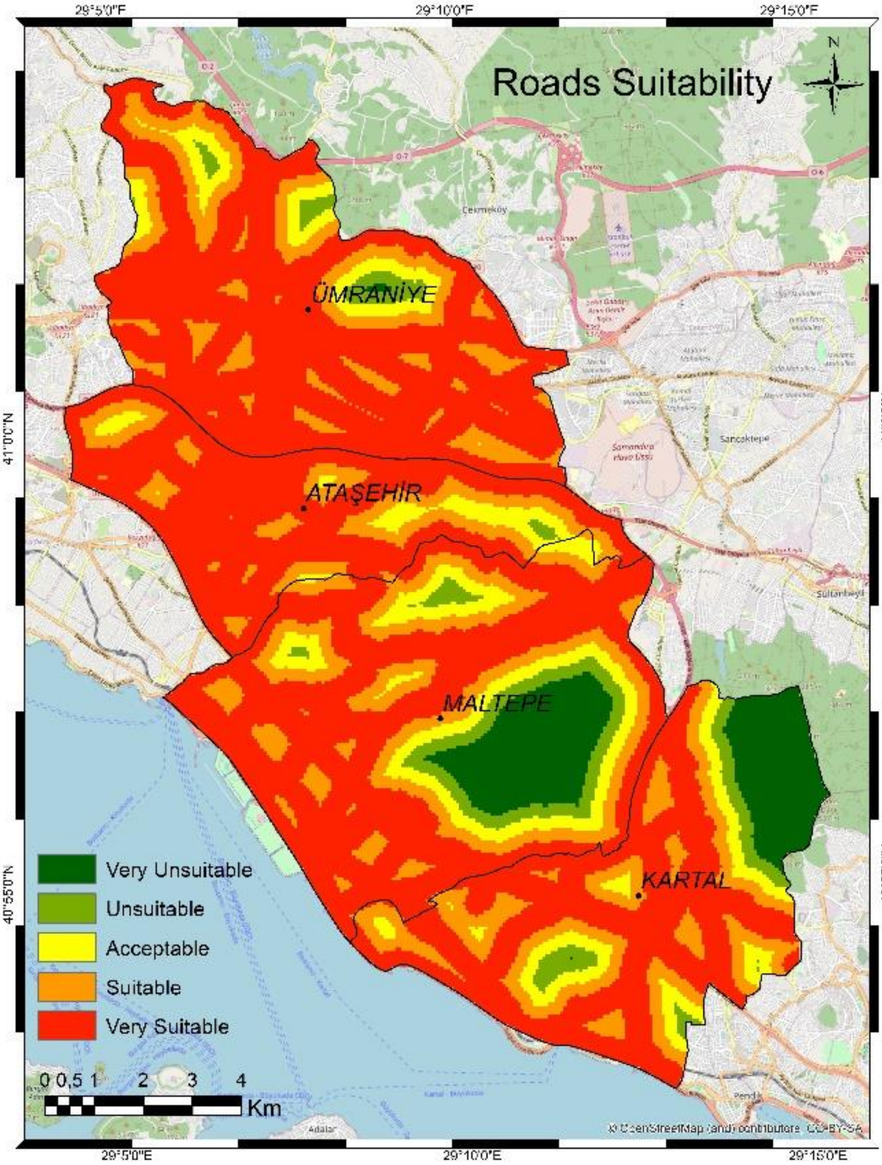

Figure 4. 5. Suitability map for the roads criterion.

Since green areas are considered an environmental factor, it is preferred that the battery station is away from green areas. Green areas are good for human health and are very important for community health, it is a fact that cities with healthy community forests are more resilient. When the suitability map of green areas is examined, Maltepe and Kartal are the districts with the highest amount of green areas (Figure 4.6). Umraniye is the district that comes after these two districts in terms of having green areas. Installing a new station in green areas does not make sense in all respects, so having green areas will adversely affect these districts.

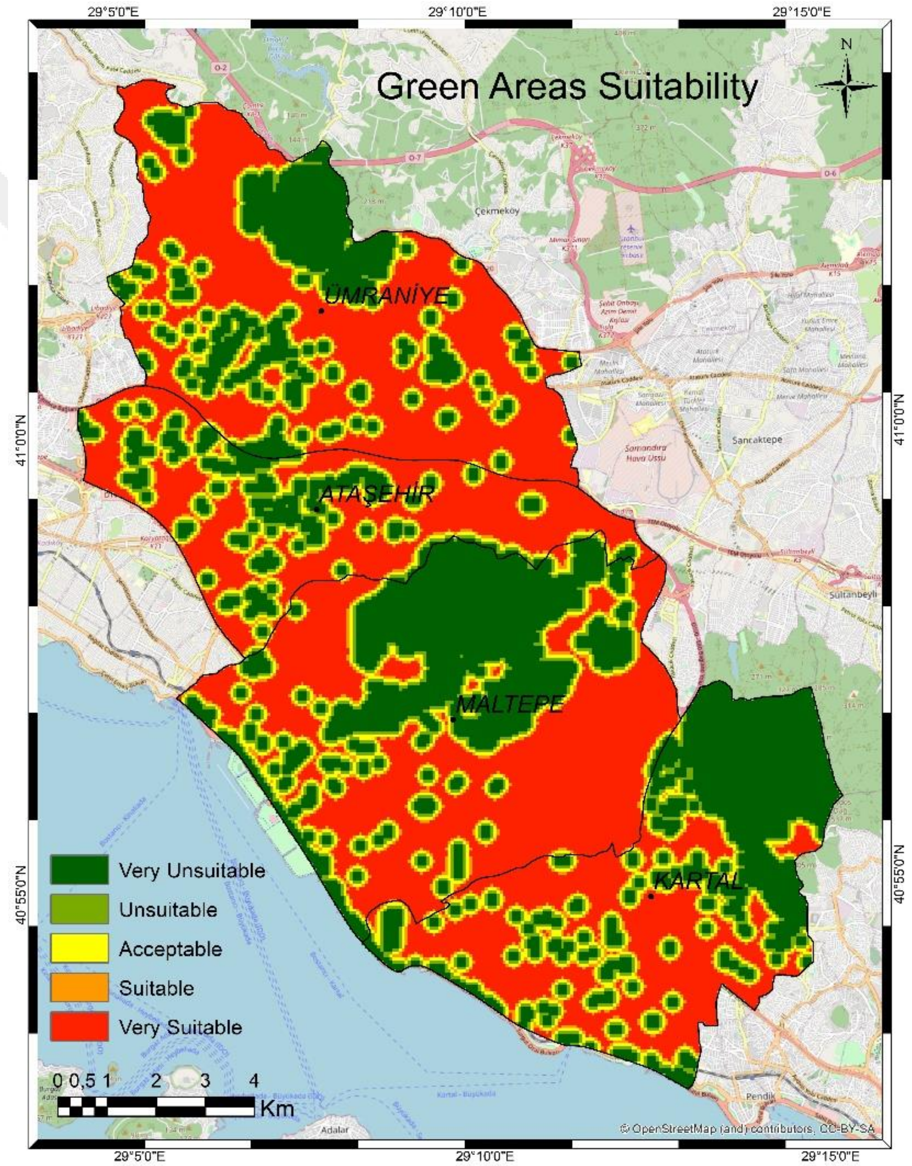

Figure 4. 6. Suitability map for the green areas criterion.

The fact that the study areas are regions with very variable land values affects new station installations, locations with low land values will be more suitable for us. The suitability map for the land values is given in Figure 4.7. Umraniye is the district with the most affordable price in terms of land values. The low land value will provide an advantage for battery station installation. It is seen that Kartal is the most suitable district after Umraniye. The district with the highest land value is Atasehir. Although Maltepe has a lower land value compared to Atasehir, it still has a disadvantage in terms of suitability because it has high prices.

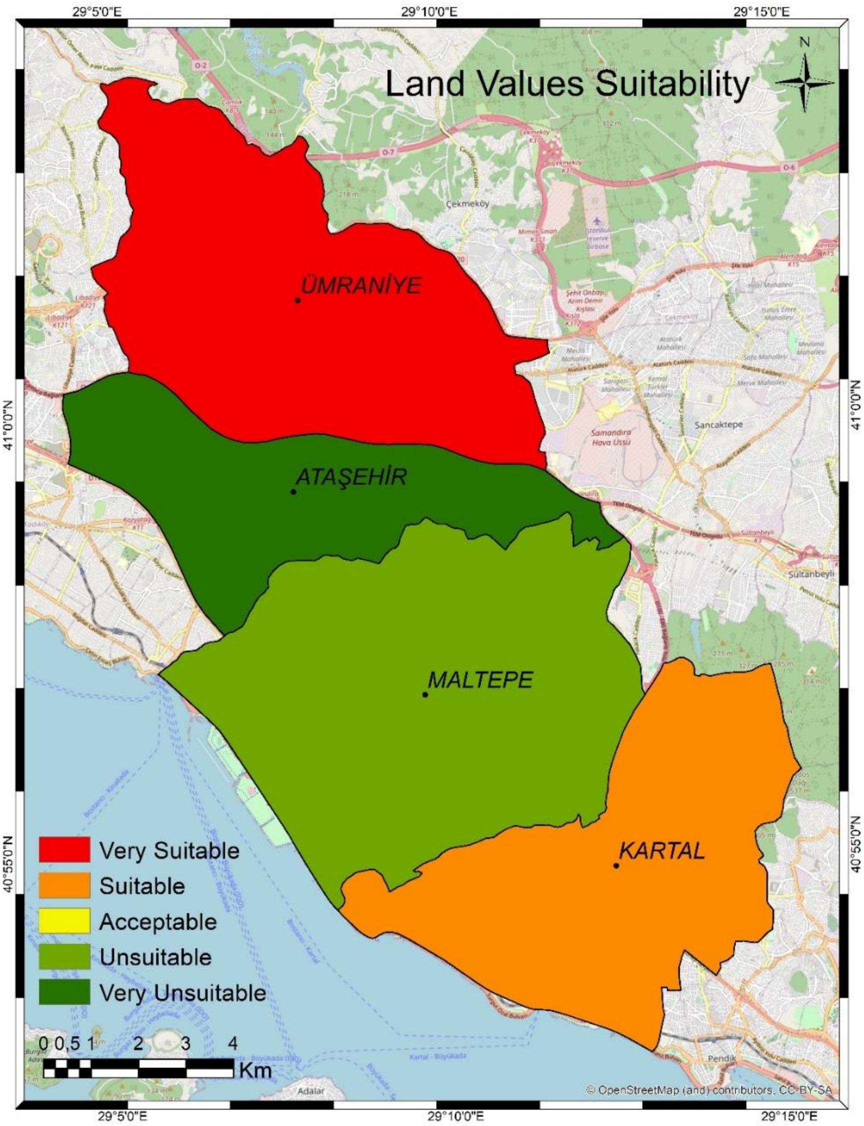

Figure 4. 7. Suitability map for the land values criterion.

The slope is taken into account in almost all studies, construction costs are high in areas with high slopes, so it is desirable to have a low percentage of slope. Although the slope seems suitable for all districts, there are regions with high slopes in some parts of Maltepe, Umraniye, and Kartal. In these regions, of course, it will not be suitable for stations (Figure 4.8).

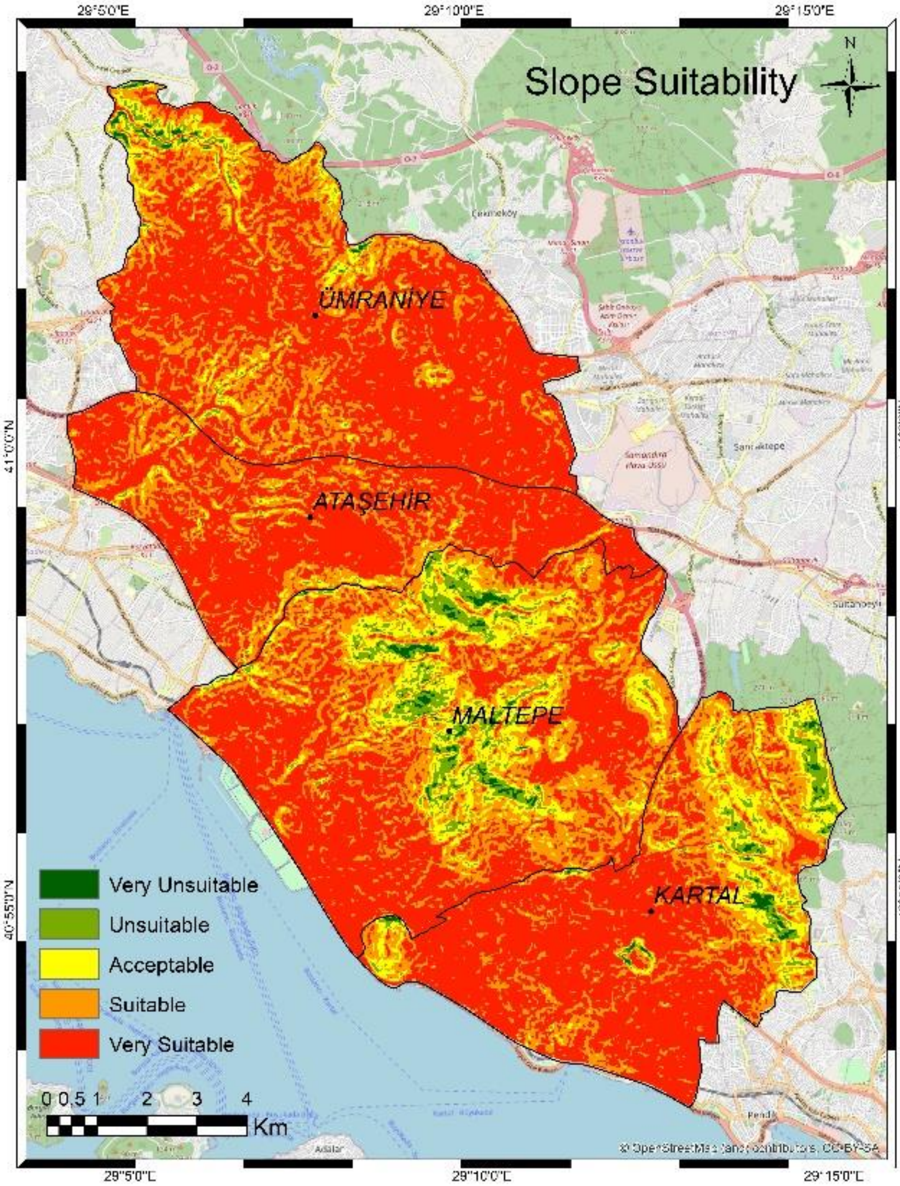

Figure 4. 8. Suitability map for the slope criterion.

4.3. Evaluation of Areas Identified in the Results Analysis

The suitability map of the areas where electric vehicle charging stations can be installed for Kartal, Maltepe, Atasehir, and Umraniye districts is created by combining the GIS and AHP method. The criteria selected in accordance with the general characteristics of the study area are combined with the ArcGIS software using the weight values obtained by AHP and the areas appropriate for battery charging station installation are decided. The EVCS suitability map acquired as a result of weighted sum analysis made by considering all the layers obtained in the study is given in Figure 4.9.

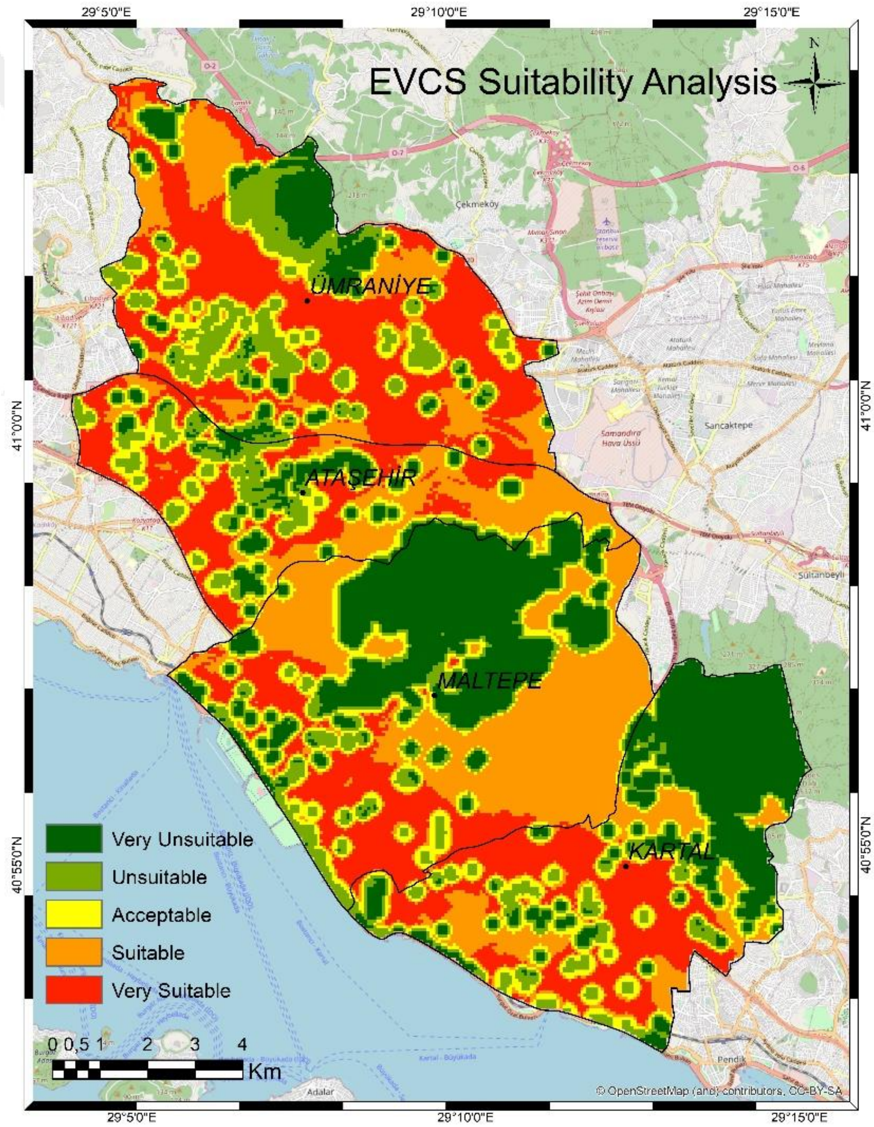

Figure 4. 9. Suitability map for EVCSs.

The areas obtained as a result of the suitability map analysis are divided into five categories; very suitable, suitable, acceptable, unsuitable, and very unsuitable areas. In the suitability map of the location selection analysis for battery stations, red-colored areas indicate the most suitable locations. Green areas are definitely the most unsuitable for battery stations. This means that as you go from red-colored areas to green-colored areas, the suitability for the battery station is reduced.

When looking at the map obtained at the end of the analysis, some areas are not suitable for the charging station. Especially in certain regions of Kartal and Maltepe districts, the most unsuitable areas are seen. The reason for this result may be that there are too many green areas in certain parts of these districts. The Aydos forests in Kartal can be said to be one of the reasons for these green areas. Kayis Mountain and its surroundings in Maltepe can be given as one of the reasons for these green areas. While the Umraniye district has areas that are not suitable for the charging station in certain regions, this area corresponds to smaller areas than Kartal and Maltepe. One of the reasons for these unsuitable areas in Umraniye is that it has a part of the Kanuni Sultan Süleyman City Forest. The red-colored (very suitable) areas on the suitability map may be places close to roads, petrol stations, parking areas, and shopping malls.

Before determining alternative station points in the study, the coordinates of the available vehicle battery stations were obtained and created a map layer. Figure 4.10 shows the current battery charging stations map. When we look at the map of the current charging stations, it is seen that there are 22 available stations, but this number will not be enough as vehicle sales increase in the coming years. It is an inevitable fact that the number of charging stations will increase with the increasing demand and vehicle sales. When the locations of the current stations are examined, it has been determined that these stations are mostly located in shopping malls, petrol stations, and car care services. There are almost no stations, especially in some parts of the Maltepe district.

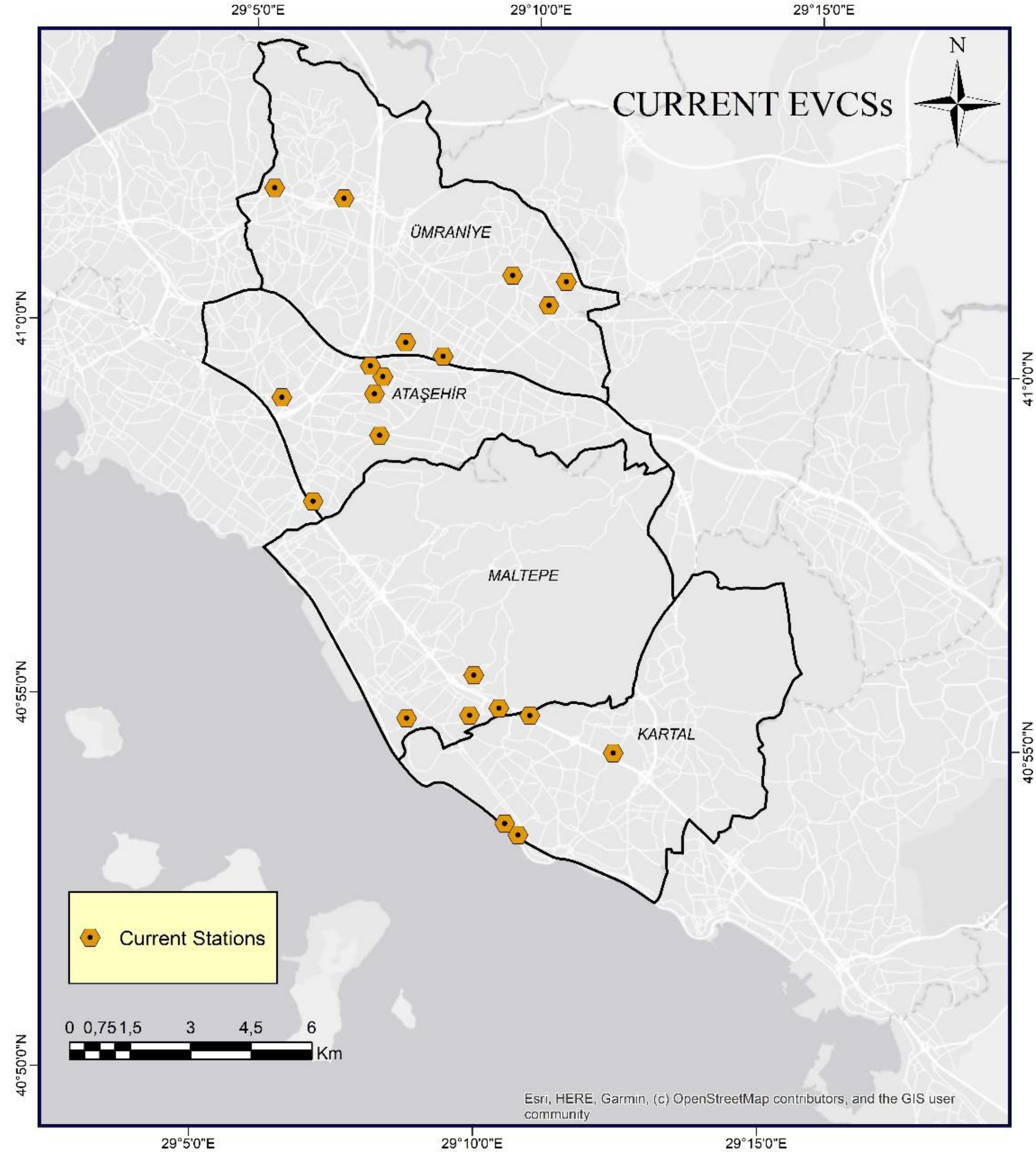

Figure 4. 10. Map of current charging stations.

Based on the maps and results obtained in the study, it was decided to choose locations of alternative stations for vehicle battery stations. These alternatives are sorted according to the final suitability. The main purpose of identifying alternative station locations is to provide an idea for newly opened stations and to demonstrate the importance of alternative stations and their surroundings as areas where the station can be required. Figure 4.11 shows the locations of alternative EVCSs, these alternative station locations are determined based on the appropriateness conditions obtained. 14 vehicle charging station points have been selected, these alternative stations are recommended for charging stations. These alternative station locations will provide us with ideas of alternative options for the new stations to be installed, and the location of the existing stations.

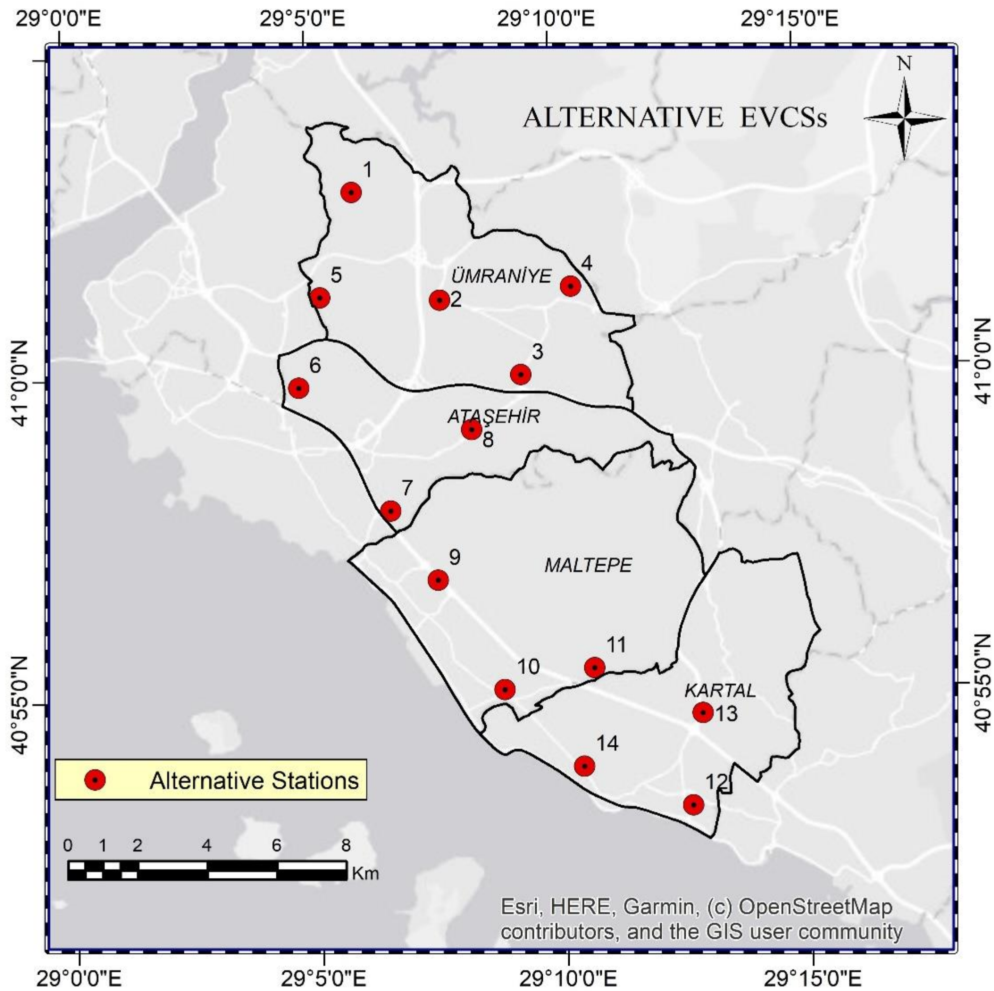

Figure 4. 11. Map of alternative stations.

5. CONCLUSIONS

Although there are many alternative transport opportunities that are more environmentally friendly and efficient, people in many countries, including Turkey, use their private cars. This causes more dependence on petroleum products. In fact, today we have sustainable technologies that can cut oil dependency. Among these technologies, electric vehicles are one of the best solutions that can give us a more sustainable world in terms of energy. EVs have both advantages and disadvantages, so a convenient and economical system must be designed to make the most of these cars.

In this study, a strategic and scientific decision-making method has been implemented to identify new potential locations for EVCSs. At the first stage of this study, three main criteria (“economic”, “accessibility” and “environmental”) and 8 sub-criteria are taken into account for the best positioning of EVCSs. In the selection of these criteria, the criteria have been decided by reviewing articles similar to the study and conducting other necessary research. In the second stage, after the geographical and other types of data required for each criterion are collected, this data is mapped using the GIS software. At the final stage, the criteria are weighed using the AHP method, and then the GIS program analyzes the weighted sum analysis of these criteria layers.

When all analyzes were completed, the suitability map of the EV charging stations was obtained as a result of the analysis. This suitability map shows us which region is more suitable for the vehicle station and which region is less suitable. Thanks to this map, suitable and unsuitable places for stations were determined. When evaluated from the results obtained, it has been determined that the reason why some regions in Umraniye, Kartal, and Maltepe districts are not suitable for charging stations is that they have green areas. In particular, the main reason for these green (unsuitable) areas is the Aydos Forest for Kartal district, the Kayis Mountain for Maltepe district, and the city forest of Kanuni Sultan Suleyman City Forest for Umraniye district.

Knowing the number of stations available and the location of stations is important in determining new station locations, so first the existing station coordinates have been obtained and a map of stations has been created using these locations. These available stations create an idea for alternative stations. When the existing stations are examined, it has been determined that the number of stations in the Maltepe district is low and there are no stations in some places. In fact, in general, it is inevitable that there are few stations in all districts. The available stations are mainly located in shopping centers, petrol stations, and car care services. When all districts are examined, it has been determined that station density is seen in some parts of each district, while there are no stations in other parts.

With the expected increase in vehicle numbers in the coming years, it is a fact that vehicle charging stations will not be sufficient. This increase and demand for vehicles will only become possible with the opening and operation of new station centers. Based on the findings acquired as a result of the study, 14 alternative station locations have been proposed. In the selection of alternative station points, a selection is made by taking into account the proximity to the roads and the most suitable places obtained in the result map. These recommended station locations may provide an idea for the newly opened stations.

6. RECOMMENDATIONS

The introduction of electric vehicles is an indication of the beginning of the end for vehicles with conventional engines. As electric vehicles are increasingly accepted, the need for battery stations for vehicles will increase. Turkey is a developing country, so it has to keep up with the development of electric vehicles. A new study on electric vehicle battery stations can be carried out for Turkey using the method used in the study. In the most crowded cities in Turkey, such as Bursa, Izmir, and Antalya, spatial analysis can be carried out using the same method. In future studies, other criteria such as construction cost, operating and management cost, transportation stations, and road potency units can be considered. In the current study, the municipality's parking areas were taken into account, all other parking areas can be taken into account in the new studies.

The methodology used in this research can also be used in other areas, such as health, education, and finance. The GIS-based MCDM method allows us to integrate many data, such as map data, numeric data, and more. Therefore, this method will contribute to our study in many areas. In recent years, studies such as pandemic hospital location selection, school location selection, and hospital location selection have gained importance. There are studies related to some of these fields of study in Turkey, but it is possible to contribute to the literature with studies covering different working areas and conducted in different regions.

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